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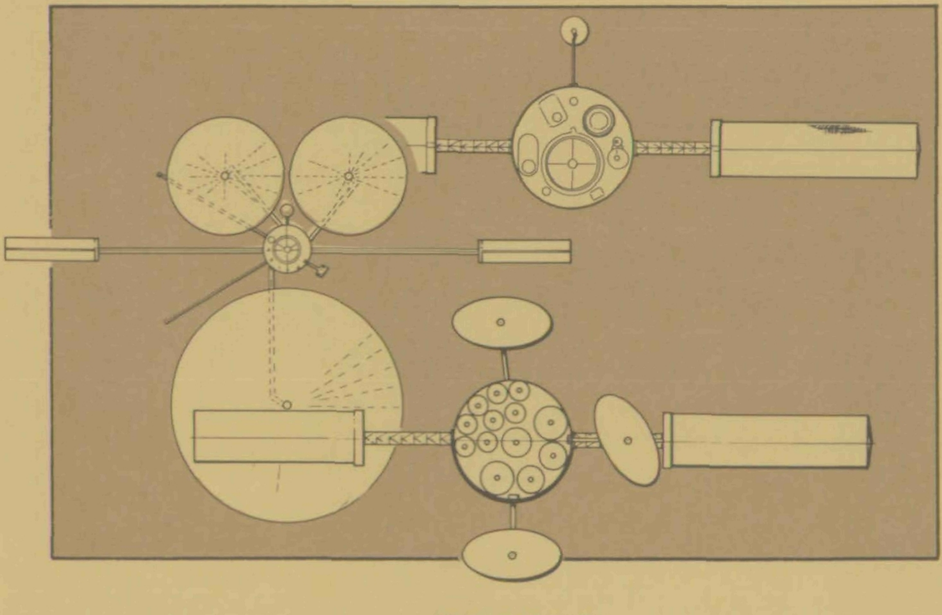
GEOSYNCHRONOUS PLATFORM DEFINITION STUDY

Volume II

OVERALL STUDY SUMMARY



JUNE 1973

Space Division
Rockwell International

12214 Lakewood Boulevard
Downey, California 90241

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H L Myers

H. L. Myers
GPDS STUDY MANAGER

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1 2 2 1 4 Lakewood Boulevard,
Downey, California 90241

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FOREWORD

The Geosynchronous Platform Definition Study was a pre-Phase A analysis conducted by the Space Division of Rockwell International Corporation (Rockwell) under Contract NAS9-12909 for the Lyndon B. Johnson Space Center of the National Aeronautics and Space Administration. The study explores the scope of geosynchronous traffic, the needs and benefits of multifunction space platforms, transportation system interfaces, and the definition of representative platform conceptual designs. The work was administered under the technical direction of Mr. David Brown (Telephone 713-483-6321) of the Program Planning Office/Future Programs Division of the Lyndon B. Johnson Space Center.

This report consists of the following seven volumes:

Volume I - Executive Summary	SD 73-SA-0036-1
Volume II - Overall Study Summary	SD 73-SA-0036-2
Volume III - Geosynchronous Mission Characteristics	SD 73-SA-0036-3
Volume IV, Part 1 - Traffic Analysis and System Requirements for the Baseline Traffice Model	SD 73-SA-0036-4 Part 1
Volume IV, Part 2 - Traffic Analysis and System Requirements for the New Traffic Model	SD 73-SA-0036-4 Part 2
Volume V - Geosynchronous Platform Synthesis	SD 73-SA-0036-5
Volume VI - Geosynchronous Program Evaluation and Recommendations	SD 73-SA-0036-6
Volume VII - Geosynchronous Transportation Requirements	SD 73-SA-0036-7

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R. D. Meston	Mission and Program Analysis
L. R. Hogan	Systems Engineering and Spacecraft Design
E. Mehrbach	Communications and Avionics
Dr. K. A. Ehricke	Advanced Mission Analysis
M. R. Schall	Operations and Traffic Analysis
J. W. Patrick	Crew Systems and Servicing Analysis
E. L. Triman	Communications
E. G. Clegg	Spacecraft Design
K. B. Roberts	Operations Analysis
A. Gianformaggio	Cost Analysis
D. W. Earle	System Integration
R. E. Ogelvie	Guidance and Control
R. P. Arras	Thermal Control
W. C. Schmill	Electrical Power
J. B. Weddell	Astro-Physics Programs
E. F. Kraly	Sensor Systems Analysis

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ABBREVIATIONS

ASCS	Attitude stabilization and control system
ATS	Applications Technology Satellite
CCD	Charge coupled device
CCIR	Consultative Committee for International Radio
CM	Crew module
C/N	Carrier-to-noise ratio
COMM	Communications
Comsat	Communications Satellite
CSM	Common support module
DMS	Data management subsystem
Domsat	Domestic Communications Satellite
ECS	Environmental control subsystem
EIRP	Effective isotropic radiated power
EPS	Electrical power subsystem
FDMA	Frequency division multiplexing
FM	Frequency modulation
GEOPAUSE	Geodetic satellite in polar geosynchronous orbit
Geoseps	Geosynchronous solar electric propulsion stage
Intelsat	International Communication Satellite
IPACS	Integrated power and attitude control system
Mersat	Metrology and Earth Observations Satellite
Navsat	Navigation and Traffic Control Satellite

OTS	Orbital transportation system
PCM	Pulse code modulation
PSK	Phase shift keying
RCS	Reaction control subsystem
RSU	Remote service unit
SATA	Small Application Technology Satellite
SEP	Solar electric propulsion
SGLS	Space-ground link subsystem (part of U.S. Air Force Satellite Control Facility)
SNR	Signal-to-noise ratio
SSM	Spares storage module
STDN	Spaceflight tracking and data network
STS	Space transportation system
TDMA	Time division multiple access
TDRS	Tracking and Data Relay Satellite
TPS	Thermal protection subsystem
TT&C	Tracking, telemetry and command
UHF	Ultra high frequency
VHF	Very high frequency
WARC	World Administrative Radio Conference
XMTR	Transmitter

1.0 INTRODUCTION

This study was undertaken to examine the feasibility of employing space platforms for geosynchronous operations. This objective was carried out by: (1) examining the nature of currently planned and new evolutionary geosynchronous programs; (2) investigating alternate ways of conducting these missions and defining the required logistics support; and (3) developing concepts for new systems to support geosynchronous programs in an effective and economical manner. The resulting data will contribute to a planning base for future space activities.

The development of low-cost concepts that meet necessary levels of performance is paramount in today's economic environment. Toward this end, geosynchronous programs offer the potential of grouping adjacent payload functions in a manner which retains their earth access geometry. Payload or function grouping offers potential economies through reduced individual spacecraft inventories and their attendant transportation costs. Additional benefits from on-orbit servicing are also possible. Serviceable spacecraft concepts are currently being explored by NASA and the industry to determine their potential application to low-cost program approaches. Added logistics benefits are possible through the concentration of servicing operations into few orbiting elements.

Potentially dramatic growth projections for geosynchronous operations contributed to the need for this study. Major growth is forecast for both domestic and international communications relay services. Enhancement of astronomy and earth-observation programs is envisioned with payloads in geosynchronous orbits. Other useful benefits, such as navigation and traffic control, can best be provided by means of geosynchronous elements. Also, new and advanced geosynchronous concepts for space power and light have been identified. The delivery and operating economies resulting from space shuttle and reusable tug operations will accelerate these geosynchronous orbit activities. Such growth projections raise questions concerning the possibility of overcrowding this limited natural resource if all functions continue to be performed by individual satellites. Planning to avoid such a condition is vital. Progress in achieving the benefits available from space must not be impeded by the lack of timely planning information.

APPROACH AND SCOPE

The basic approach taken in this study was to define two geosynchronous traffic models and to develop a logical pattern of subsequent analyses leading to the definition of system requirements and conceptual platform designs for each model. The first, called the "baseline traffic model" was based upon current NASA mission planning information, notably the updated NASA Mission Model, 6 June 1972. The second, the "new traffic model", was derived during

the study from forecasts and demand models of individual user functions. Each model was separately analyzed with the following objectives:

1. To determine the nature and degree of satellite congestion it represented

2. To determine the grouping capability of geosynchronous payloads into multifunction units

3. To define system level requirements, including variations in on-orbit servicing modes

4. To establish representative platform conceptual designs

Alternative geosynchronous programs were defined using various configurations and operational modes, which were then evaluated to determine a recommended geosynchronous program approach. Later, attention was focused on transportation interfaces in order to define the desired match between geosynchronous platforms and transportation system elements.

As shown in Figure 1-1, the study was divided into six basic task areas, five of which were further organized into two parts for the two traffic models. The principal task flow is sequential within each set of traffic model oriented analyses as depicted by the solid arrows linking study blocks. A lesser relationship, mostly task methodology, exists between the two traffic oriented parts of each task as depicted by the dashed arrows. This pattern of task interrelationships preserves the traceability of platforms and programs to the baseline traffic model which has received widespread use throughout NASA as a planning and analysis tool.

Task 1.0 comprised all the efforts leading to the construction of the new traffic model. Task 2.0 provided basic geosynchronous orbit characteristics and EM spectrum utilization data for use in other task areas. Orbit saturation analyses were conducted in Task 3.0. Satellite distributions for each traffic model were analyzed for low crowding and potential physical or EM interference conditions. Task 4.0 produced functional grouping options and resultant system level requirements for space platforms including remote and manned on-orbit servicing modes. Physical, functional, and operational interface requirements between platforms and the transportation system were also determined. Conceptual platform designs were synthesized in Task 5.0. Emphasis was on configuration features favoring evolution from auto-remote to manned servicing concepts. Preferred concepts for platform/transportation interfaces were established. Program options and evaluations utilizing the platform configurations and servicing modes derived in the study were structured in Task 6.0. Evaluation results, along with key findings from all study tasks, were used for the derivation of a recommended geosynchronous program approach.

The study was accomplished and documented during the 12-month period from 26 June 1972 to 29 June 1973. The study results are recorded in seven basic volumes. Volume I is an executive summary briefly outlining the objectives and summarizing the results, conclusions, and recommendations; Volume II is an overall study summary enlarging upon the materials covered

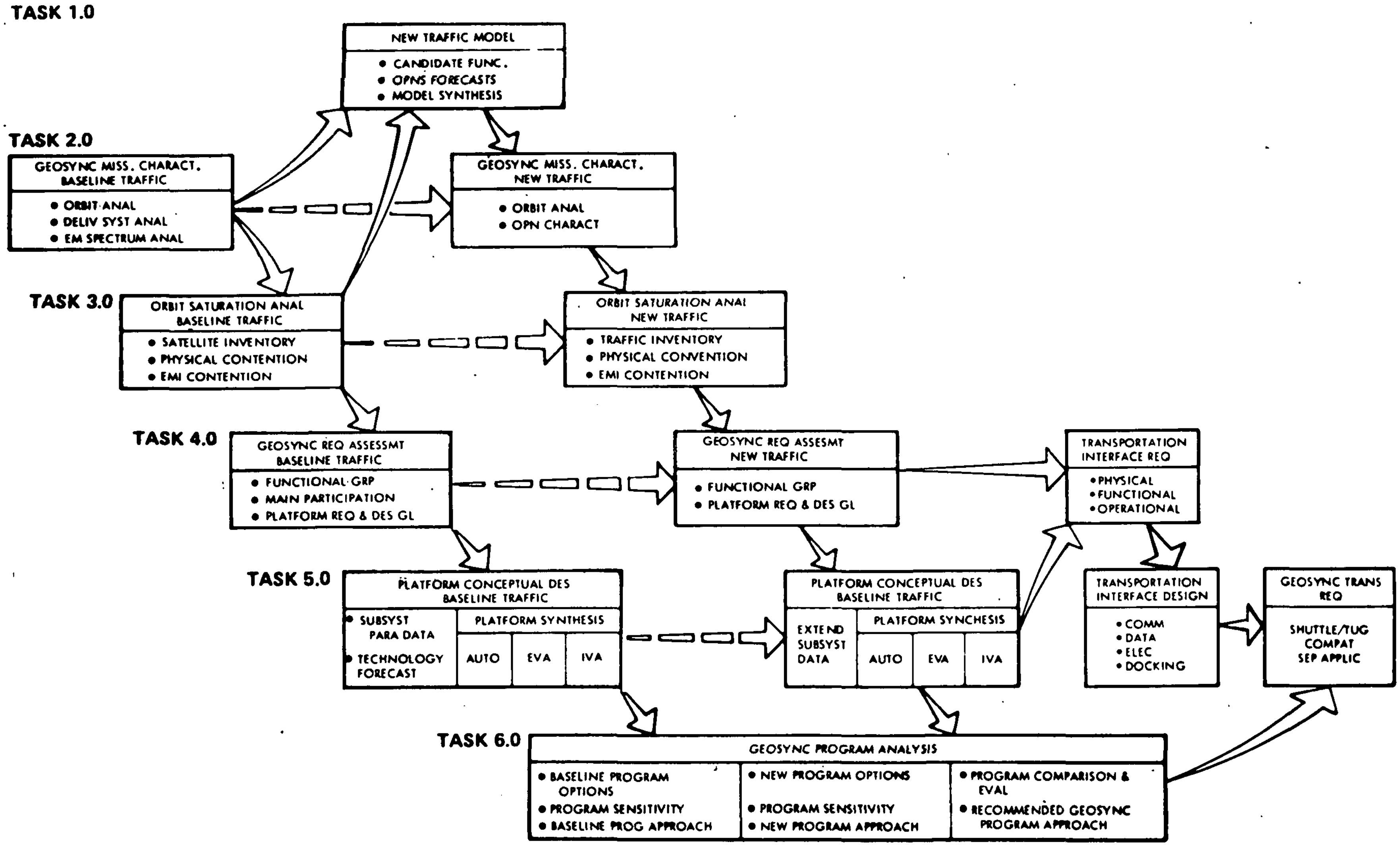


Figure 1-1. Geosynchronous Platform Definition Study Logic

in Volume I and including all important results and their principal supporting data. Volume III compiles the orbit characteristics and EM spectrum data from Task 2.0 into a convenient source for future use outside of this study in other advanced mission planning activities. Volume IV contains a comprehensive description of the traffic analysis and system requirements, for each traffic model, from Tasks 3.0 and 4.0. Volume V describes the platform conceptual designs synthesized in Task 5.0; Volume VI presents the program options and evaluations conducted in Task 6.0; and Volume VII summarizes the transportation interface analyses subsequently added to the study.

This volume is organized to provide a rapid but thorough understanding of the complete study. The individual sections are patterned around the principal study tasks and highlight key analyses, results, and conclusions. Principal findings and the recommended program approach are located in Section 2.0 for convenience. Basic mission characteristics data are presented in Section 3.0. Traffic models are defined in Section 4.0, along with their supporting derivations. Orbit saturation analyses and methodology are included in Section 5.0. Section 6.0 summarizes platform requirements and the subsequently generated conceptual designs. The transportation interface analyses that were added to the study and their supporting design efforts are summarized in Section 7.0. Section 8.0 summarizes programmatic trades and defines the recommended geosynchronous program approach. Section 9.0 is a list of references.

2.0 PRINCIPAL FINDINGS AND RECOMMENDED PROGRAM APPROACH

The key finding of this study contract was that geosynchronous space platforms are not only feasible, but also practical in their potential for cost savings, increased utilitarian services, and technical benefits. From the study evaluations and from earlier traffic analysis and platform synthesis activities, the following principal conclusions and findings were derived:

- Selected groupings of functions/payloads on platforms are feasible and desirable.
- For each major function, single platform designs capable of operating with any of three servicing modes (remote, EVA, shirtsleeve) appear feasible.
- Both remote-serviced and man-attended programs with multi-function platforms offer significant cost savings over conventional programs with expendable satellites, even with the high servicing levels assumed.
- Platforms are cost effective because of hardware commonality and reduced inventories.
- Standardized packaging is feasible for all platform subsystems and most mission equipment.
- With appropriate functional grouping, a single utilities support module design can economically support all defined geosynchronous payloads. It also offers the likely capability of supporting development and technology payloads that are yet to be defined.
- The new traffic model is more representative of the full potential for geosynchronous operations than the baseline model. It is based on global demands, and provides increased utilitarian benefits to mankind.
- Satellite physical contention is not likely to be a critical problem through the 1990 time period, even without retrieval.
- Geosynchronous EMI contention will likely occur before 1990 if wider spectrum usage is not employed by communications relay systems. Platforms using both C- and K-bands would eliminate this problem.

- S-band EMI problems currently exist among users in all orbits and will be compounded by increased space traffic. Geosynchronous platforms would aid in reducing these problems by lowering the number of traffic elements.

- Cooperation and planning will be required on both national and international levels to preclude physical and EMI contention.

- With relatively minor modifications, the baseline shuttle and tug capabilities* can meet the transportation needs of the geosynchronous programs defined during the study.

- Application of a solar electric propulsion stage to geosynchronous platform programs is feasible and offers increased payloads, but only at the expense of operational complexities associated with payload exchange operations and long trip times.

RECOMMENDED GEOSYNCHRONOUS PROGRAM APPROACH

The more significant conclusions of the study are that grouping of functions or payloads is feasible and that on-orbit servicing offers potential gains in shuttle/tug utilization efficiency, and further, that it is possible to design platforms offering the flexibility of operating with all three servicing modes, mechanical-remote, EVA/IVA man-attended (pressure suited), and shirtsleeve man-attended. Thus, a program approach which emphasizes selected groupings of payloads, tailored to standardized support levels and related hardware packaging, and which offers the flexibility for accommodating various servicing modes, is recommended. This holds open the option for future decisions on preferred servicing modes based on added experience in both serviceable spacecraft design and actual servicing operations. The inherent capabilities of man in situ may prove to be the dominant factor in establishing the preferred servicing concept.

The pre-Phase A study shows only the basic characteristics of the desired program approach. Future efforts are required to translate this general approach into specific development activities. Geosynchronous traffic and related mission equipment must be better defined, payload grouping options must be refined and further developed, common support requirements must be sized to match the improved traffic definition and the new grouping options, on-orbit servicing techniques must be developed and, the corresponding modularized hardware designs must be synthesized.

*Shuttle payload is 65,000 pounds. Tug round-trip payload to geosynchronous orbit is 3225 pounds.

3.0 GEOSYNCHRONOUS MISSION CHARACTERISTICS

The general characteristics of geosynchronous missions were defined and examined so that earth coverage, spectrum utilization phenomena, and related operational features required in other task areas could be determined. Basic parametric data and analytical relationships governing these phenomena were derived for application to the specific missions and functions contained in the traffic models. The resulting fundamental data are intended to be useful for other advanced mission planning activities as well as the ones in this study. These data were organized and documented separately in Volume III, which emphasizes the derivation and use of the data.

The defined mission data include the ground-trace and earth-coverage characteristics of geostationary, inclined, and other related geosynchronous orbits. Line-of-sight geometries were determined, along with preferred satellite locations for various representative surface aim points and coverage zones. Earth-sun-satellite geometry patterns were defined which affect solar noise levels in communication links and which define periods of solar occultation where solar array power output is reduced or terminated. Orbit perturbations were defined and their effects on orbital motions summarized. Delta-V requirements to offset these perturbations were also derived. Mission profile characteristics were constructed depicting all the major events required to place payloads at any specified location in geosynchronous orbit. Both placement and retrieval were considered, along with their respective delta-V budgets. Spectrum data included the definition of the usable spectrum in terms of natural phenomena effects (atmosphere and weather), frequency allocations through international agreements, and available technology. Important coverage enhancement and improved spectrum utilization factors were developed through frequency reuse techniques.

MISSION CHARACTERISTICS DEFINITION

Fundamental mission characteristics data were developed for both geosynchronous and related orbits. In the context of this study, geosynchronous orbits are defined as circular orbits that have a period equal to the mean rate of rotation of the earth. Included within this family of orbits are both geosynchronous equatorial (geostationary) and inclined circular orbits. Noncircular "24-hour" orbits were considered to be within the family of related orbits.

The basic relationships defining the characteristics of geosynchronous orbits are derived, fundamental characteristics are discussed, and specific data for selected cases are presented in Volume III. These data constitute the fundamental geosynchronous mission characteristics that were used throughout the study for (1) defining preferred satellite locations for a variety of spacecraft types and/or mission functions, (2) defining the number of spacecraft required to satisfy earth-spacecraft line-of-sight requirements,

(3) developing the time-phased geographic distributions of the satellites defined in the study traffic models, and (4) conducting geosynchronous orbit saturation analyses.

Orbit and Earth Coverage Characteristics

The general characteristics of geosynchronous orbits are most simply defined in terms of the ground trace of the subsatellite point. These characteristics, plus the general earth-viewing geometry, define the earth coverage which is achievable. A representative family of geosynchronous orbit ground traces are shown in Figure 3-1, in which a geographic longitude of the ascending node of zero degrees is assumed. As can be seen from the figure, the ground trace is, in general, described by a "figure eight" with the longitudinal excursion of the trace increasing with increasing inclination. Also, the absolute value of the latitude extrema is equal to the orbit inclination. The only exception is a geosynchronous orbit with an inclination of zero degrees. Spacecraft in these geostationary orbits appear to have no relative motion with respect to a stationary observer on the earth.

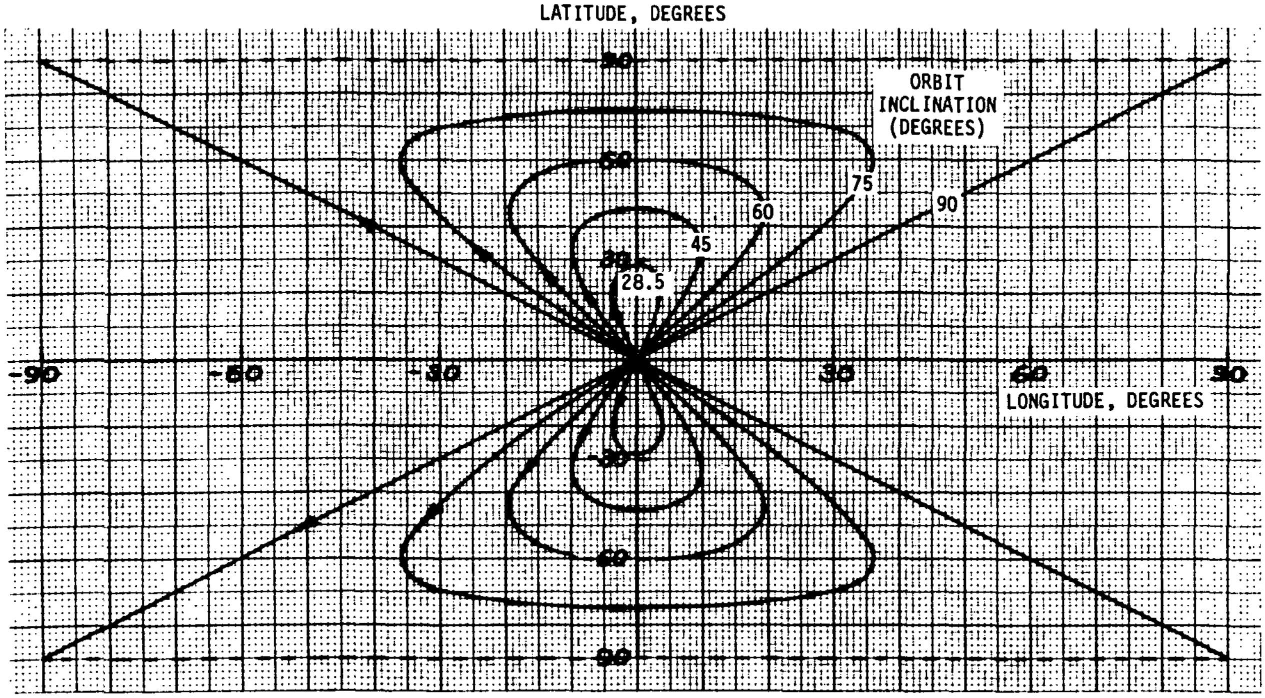


Figure 3-1. Geosynchronous Orbit Ground Trace ($\lambda_0 = 0$)

The general earth-spacecraft viewing geometry and the resultant general earth-viewing characteristics are shown in Figure 3-2. As can be seen from the earth-spacecraft viewing geometry, the viewing characteristics are dependent upon the minimum allowable surface incidence angle (α). (For earth-spacecraft communications, the surface incidence angle corresponds to the ground station mask angle.) For example, all points on the earth within a minor circle defined by an earth central angle of 152.67 degrees will be

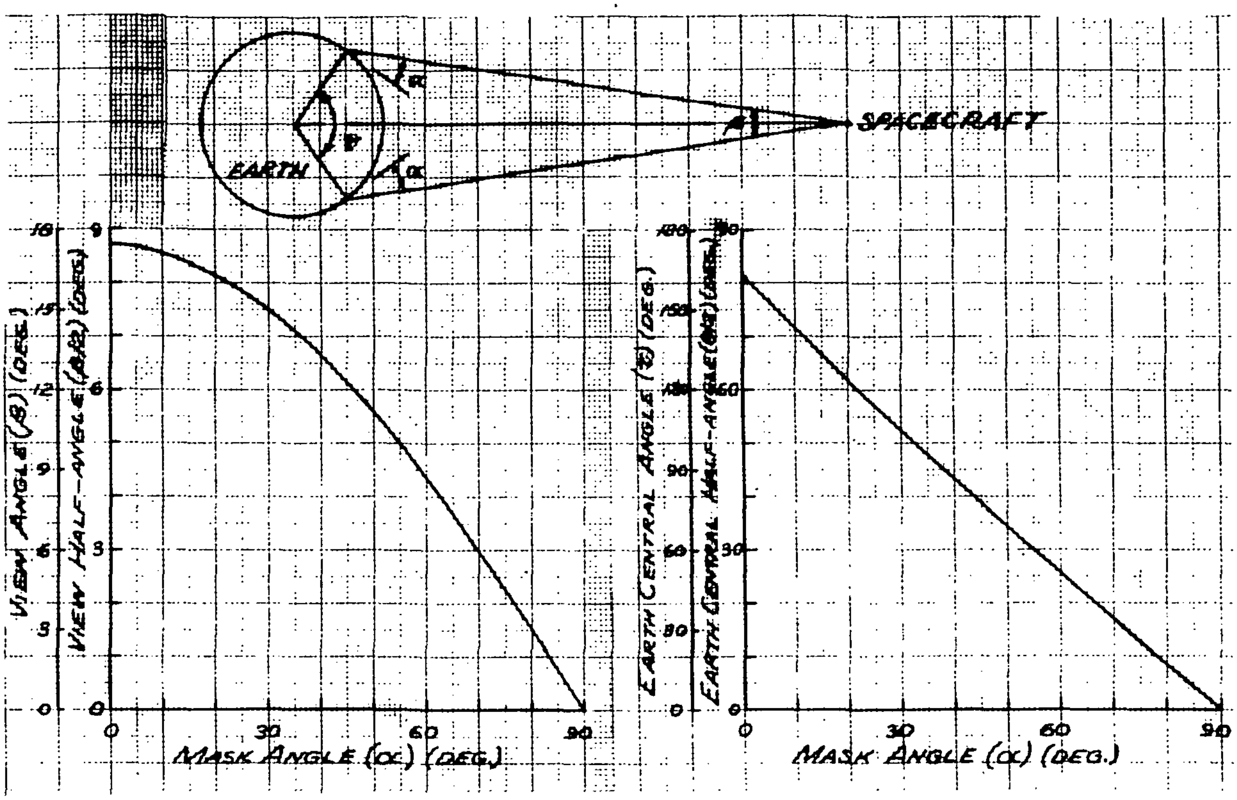


Figure 3-2. Earth-Spacecraft Viewing Characteristics

within line of sight with a surface incidence angle greater than or equal to 5 degrees. Increasing the minimum allowable incidence angle to 10 degrees results in a decrease in the total earth coverage which is achievable. For this case, the total earth coverage is described by a minor circle defined by an earth central angle of 142.87 degrees.

Representative earth coverage characteristics are shown in Figure 3-3 for a geosynchronous equatorial ($\iota = 0$) orbit. For this figure, the spacecraft geostationary location was arbitrarily assumed to be at a geographic longitude of 100°W. The coverage provided by other geostationary satellites can be obtained by translating the coverage traces along the equator.

Multiple geostationary satellites provide overlapping coverage with the magnitude of the overlap dependent upon the longitudinal separation of the spacecraft. The coverage overlap can be defined in terms of the maximum latitude of overlapping coverage as illustrated in Figure 3-4. From this figure, the maximum latitude of continuous coverage can be determined as a function of the number of spacecraft in a multiple spacecraft network assuming a uniform longitudinal distribution. For example, a four-spacecraft network with a spacecraft separation of 90 degrees can provide total and continuous coverage between 70.5°S and 70.5°N with a minimum surface incidence angle of 5 degrees.

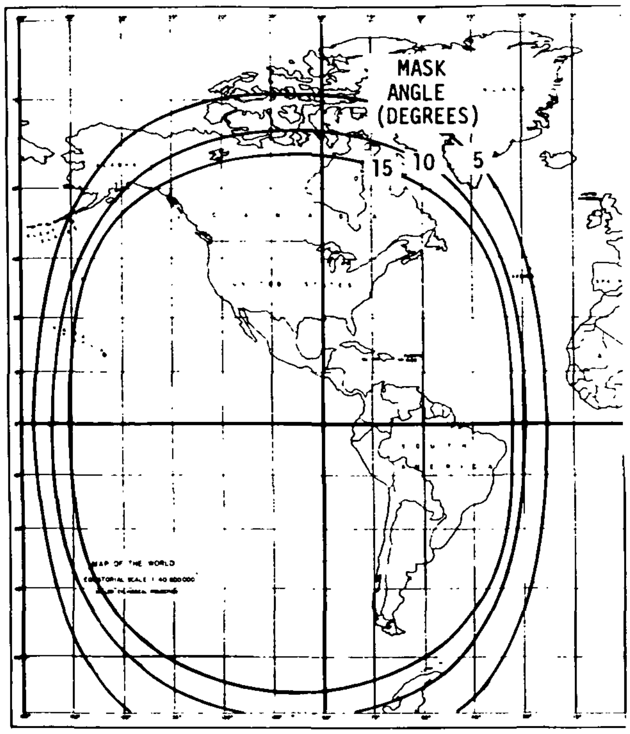


Figure 3-3. Earth Coverage Characteristics (ι = 0)

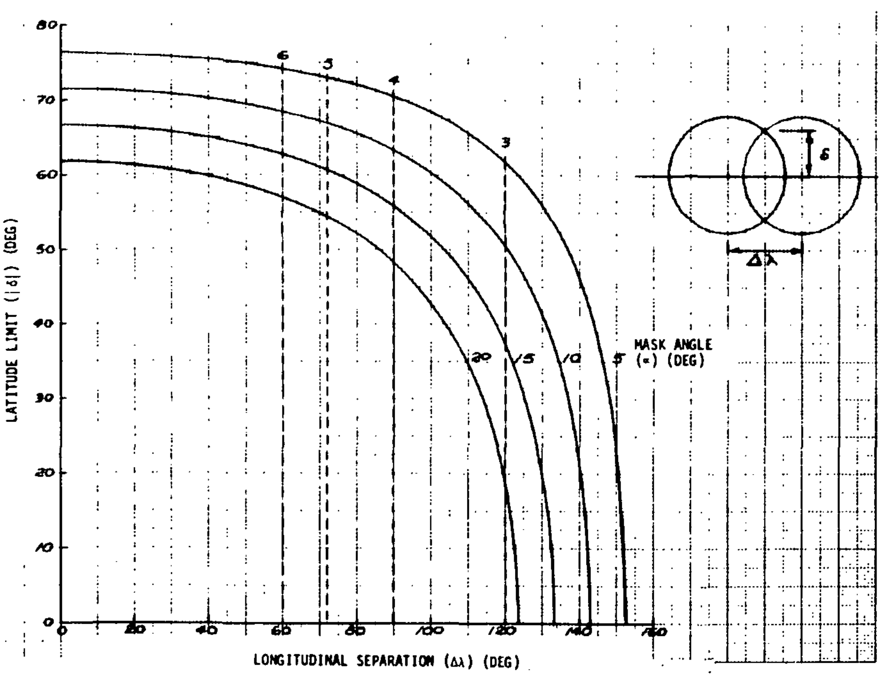


Figure 3-4. Latitude Limits for Overlapping Coverage (ι = 0)

As can be seen from Figure 3-3, coverage of the polar regions cannot be provided by geostationary satellites. It is necessary to utilize non-geostationary orbits for coverage of the polar regions. As shown in the discussion of the ground trace characteristics of geosynchronous orbits, the ground trace of a non-geostationary orbit appears to describe a figure eight. Therefore, the coverage characteristics are a function of time, and the time-phased coverage characteristics vary with inclination.

The general pattern of earth coverage characteristics provided by inclined geosynchronous orbits is illustrated in Figure 3-5. Four basic types of coverage generally exist. A region of continuous coverage (1) exists with dimensional characteristics dependent upon the orbit inclination and the ground station mask angle. The second region (2) is that surface area which is never within line of sight. The remaining regions (3 and 4) are periodically within line of sight, with the duration of visibility dependent upon the orbit inclination, the mask angle, and the relative location within the regions. Ground stations (or terrestrial traffic elements, ships, aircraft, etc.) in region 3 are within line of sight during a single continuous period of less than 24 hours each day. Ground stations within region 4 have two periods each day when a geosynchronous satellite will be within line of sight. The two daily periods are, in general, unequal, the exception being sites along the equator viewing a satellite in a circular, inclined 24-hour orbit. These sites will be within line of site during two equal periods each day.

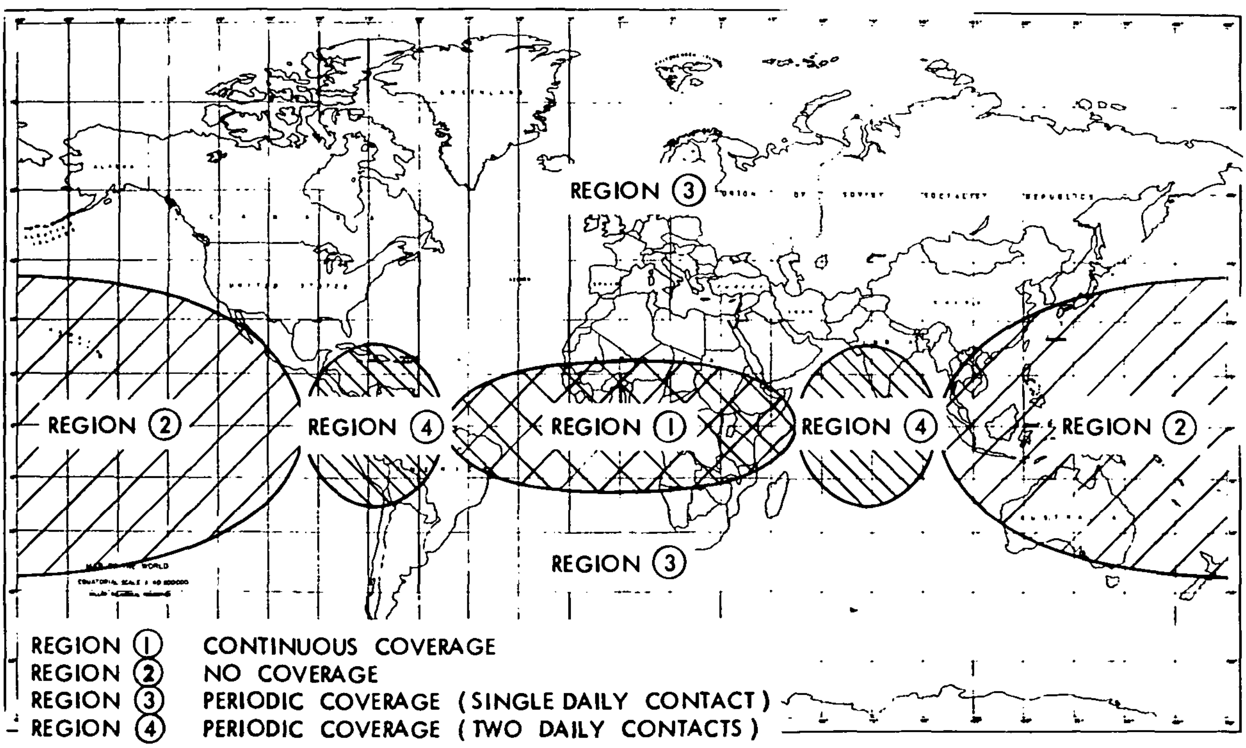


Figure 3-5. Generalized Time Varying Earth Coverage Characteristics ($\iota \neq 0$)

Preferred Satellite Locations

The preferred locations of geosynchronous satellites with respect to the earth are dependent upon the satellite coverage and ground trace characteristics and upon the geographic area or areas which must be within line of sight of the satellite. For inclined geosynchronous orbits, the duration of line of sight must also be considered since the earth coverage characteristics of inclined orbits vary with time.

The fundamental geometric considerations for establishing preferred geosynchronous satellite locations are illustrated in Figure 3-6. The resultant allowable relative longitude is shown in Figure 3-7 as a function of the geographic latitude of the ground site for a range of surface incidence angles. For a surface incidence angle (α) of five degrees, the limiting earth central angle ($\tau/2$) is 76.33 degrees. Therefore, a geostationary satellite, or an inclined geosynchronous satellite when at either the ascending or descending node, will be within line of sight of points on the earth equator between plus or minus 76.33 degrees of the subsatellite point. Also, the maximum latitude that will be within line of sight is also 76.33 degrees at a relative longitude of zero.

The allowable geographic longitude limits for geostationary satellites were developed for a representative set of geographic locations within major world-wide geographic areas. For example, 14 locations were used to grossly define the limiting geographic boundaries of Canada and the United States (including Alaska and Hawaii). The basic characteristics and utility of these data are illustrated in Figure 3-8. For this illustration, three specific sites have been chosen: Inuvik, Northwest Territories, Canada; St. John's, Island of Newfoundland; and London, England. In this example, a Canadian domestic satellite (Domsat) must be located between 122 degrees west longitude and 83 degrees west longitude if total coverage of Canada, from Inuvik to St. John's, is required. Canadian Domsats which are west of this longitude band will exclude coverage of the western parts of Canada. The other example shown in Figure 3-8 illustrates the required geographic longitude of an international communications satellite (Intelsat) for communications between St. John's, Canada, and London, England. Communications between St. John's and London can be provided via an Intelsat satellite located anywhere between 78 degrees west longitude and 17 degrees east longitude. If a more westerly Canadian ground site is required, the allowable eastern limit of the satellite location must be decreased. Also, if more easterly sites within Europe must be considered, the western limit quoted above must be decreased.

A summary of the preferred satellite locations for world-wide coverage is shown in Figure 3-9. The satellite locations are representative only, since they will be dictated by the particular earth coverage requirement.

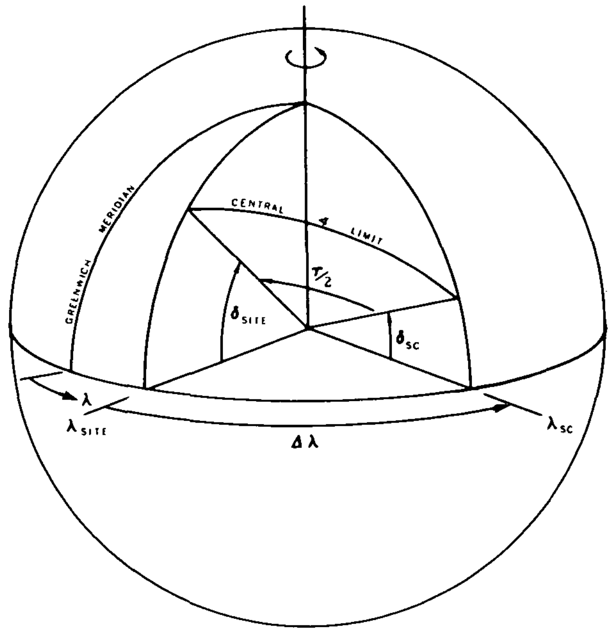


Figure 3-6. Definition of Geostationary Satellite Limits

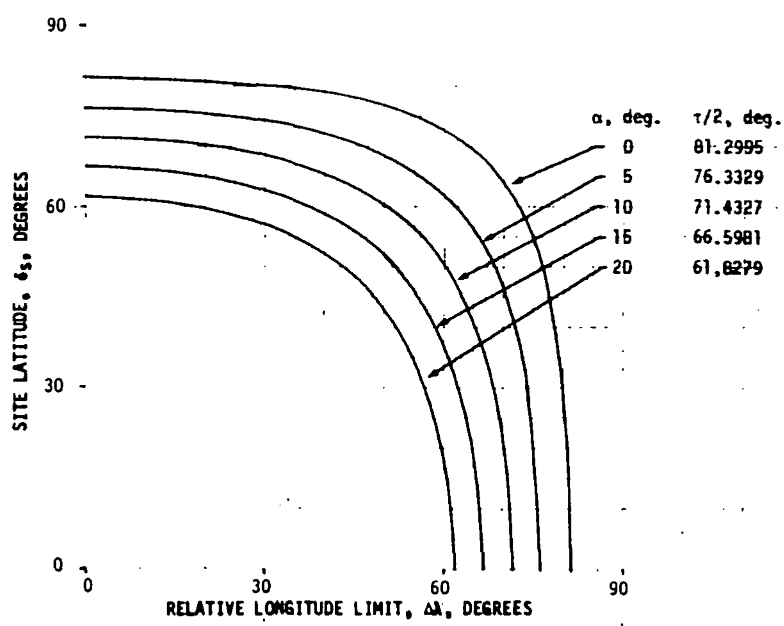
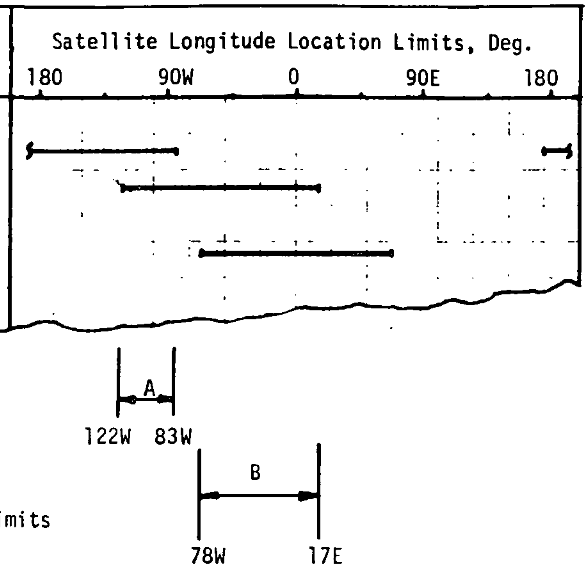


Figure 3-7. Geosynchronous Satellite Relative Longitude Limits

Geographic Area	Location	Latitude Degrees	Longitude Degrees
Canada	Inuvik	68.0 N	133.8 W
Canada	St. Johns	47.4 N	52.8 W
England	London	51.3 N	0.1 W



A: Canadian Domsat Location Limits

B: England to Canada Intelsat Location Limits

Figure 3-8. Satellite Location Limits

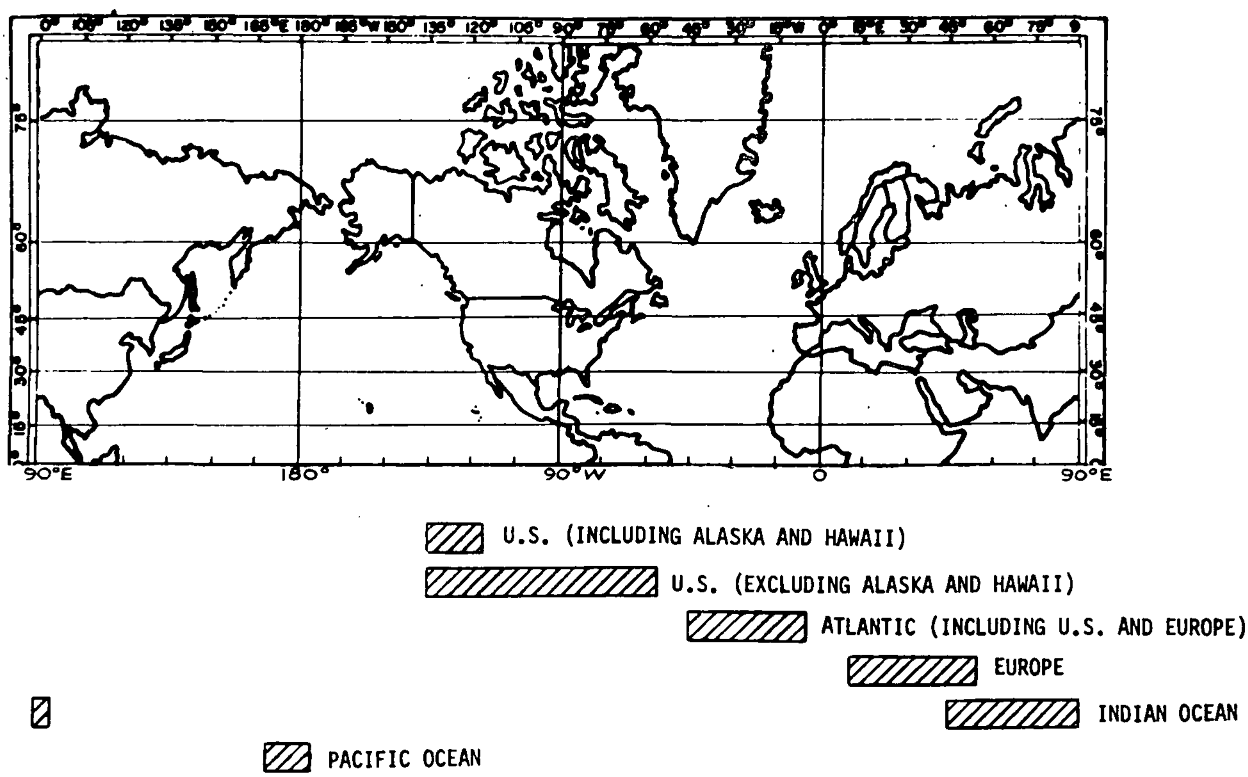


Figure 3-9. Geostationary Satellite Location Summary

Orbit Perturbation Effects

The principal perturbations which must be considered for geosynchronous orbits are those resulting from the tesseral harmonic term in the gravitational potential function of the earth, to the moon and sun (luni-solar), and to solar pressure. The tesseral harmonic term produces an apparent longitudinal "drift" about one or two stable points (75°E and 105°W longitude), with the amplitude of the drift being equal to the initial displacement from the stable point. The luni-solar perturbations produce long-term variations in orbit inclination with specific characteristics dependent upon the initial orientation of the orbital plane. Solar pressure perturbations produce a cyclic variation in the orbit eccentricity.

The perturbations produced by the tesseral harmonic term in the earth potential result in an effective geographic longitudinal oscillation about the major axis of the earth and a radial oscillation about the mean geosynchronous altitude. These effects are as illustrated in Figure 3-10, assuming no spacecraft initial position or velocity errors. As illustrated, the spacecraft longitudinal oscillation about the equatorial major axis (stable axis) has an amplitude equal to the initial longitudinal displacement from the stable axis (located at 75°E or 105°W longitude). The approximate period of the oscillation varies from two to eight years depending upon the initial displacement from one of the stable points.

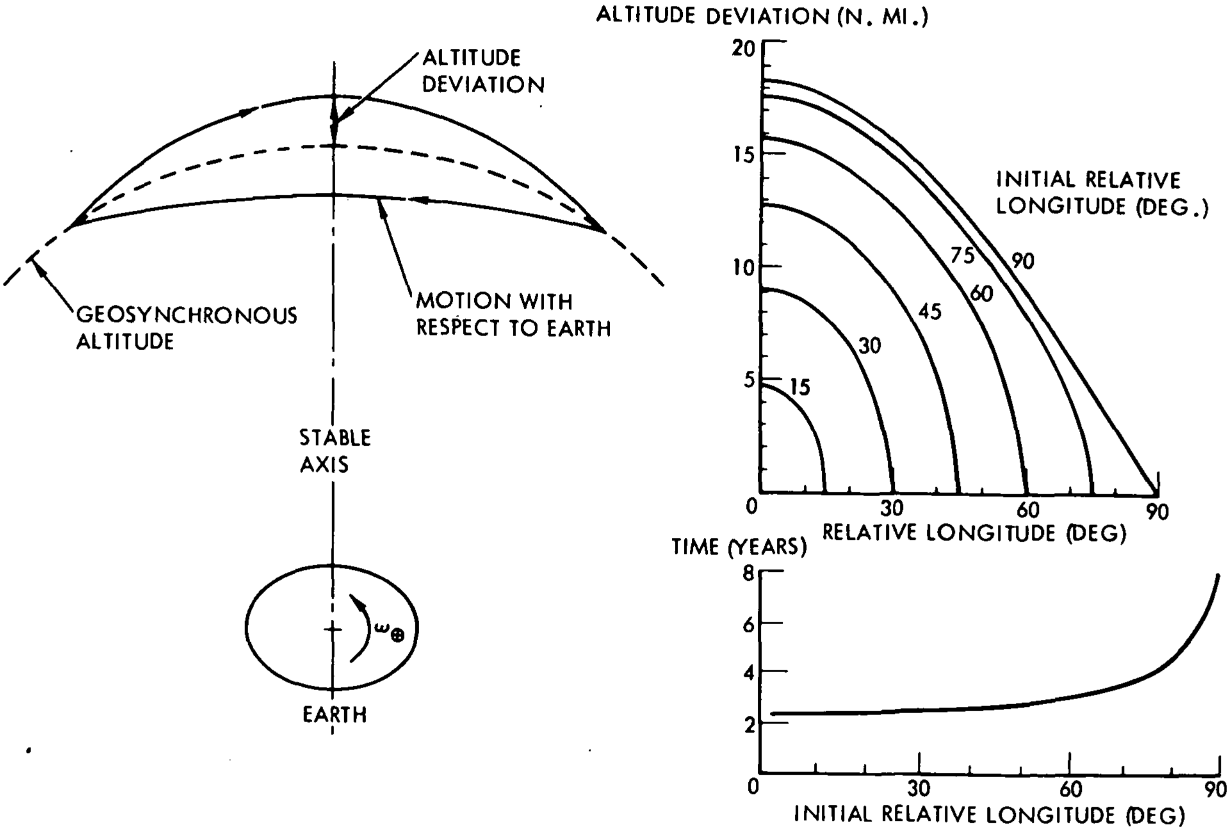


Figure 3-10. Tesseral Harmonics Perturbations
(Residual Velocity Error = 0)

The radial oscillation about the mean geosynchronous altitude has the same period as the longitudinal oscillation and its amplitude is a function of the initial displacement. As shown in Figure 3-10, the maximum radial oscillation amplitude is approximately ± 18 nautical miles with respect to the mean geosynchronous orbit altitude and occurs when the initial displacement from one of the stable points approaches 90 degrees.

Luni-solar perturbations cause a long-term oscillation of the geosynchronous orbit inclination. Because of the long period of the cycle (over 50 years), luni-solar perturbations of geosynchronous orbits are usually approximated as a simplified secular motion. The mean geosynchronous orbit motion due to these perturbations is similar to the regression of the orbit of the moon due to the gravitational effect of the sun. For geosynchronous orbits, however, the orbit regression is with respect to a reference plane inclined approximately 7.3 degrees with respect to the equatorial plane.

The resultant orbit inclinations are illustrated in Figure 3-11 for two initial orbit inclinations. The inclination of an initial equatorial orbit ($\iota_0 = 0$) would be 7.3 degrees with respect to the reference plane and would retain this inclination. As a result, the inclination with respect to the equator varies from zero to a maximum of 14.6 degrees and back to zero in approximately 53 years. The variation in the inclination with respect to the equator of initially non-zero inclination orbits ($\iota_0 \neq 0$) is dependent upon the initial right ascension of the geosynchronous orbit ascending node. For the worst-case initial orientation, the inclination varies from ι_0 + 14.6 degrees over a period (>53 years), which is a function of the initial inclination (ι_0). This characteristic is illustrated in Figure 3-11 by the case in which the initial inclination is 5 degrees and the initial right ascension of the ascending node is 180 degrees. As can be seen from the figure, the inclination with respect to the equator will reach a maximum of 19.6 degrees after approximately 27 years.

Solar pressure produces a cyclic orbit-eccentricity perturbation whose magnitude depends upon the satellite area-to-weight ratio. Since the direction of the perturbing force sweeps through 360 degrees as the earth orbits the sun each year, the maximum eccentricity deviation occurs six months after the end of active (stationkeeping) operations. The perturbing force sweeps through the opposite hemisphere and nulls its effects during the last half of the year, and the orbit is again circular after the full year.

The eccentric orbits produce an apparent longitudinal libration with respect to the earth, since the angular motion of an eccentric orbit is not constant. The libration magnitude is also dependent upon the satellite area-to-weight ratio and occurs when the eccentricity perturbation is maximum. For an Intelsat IV, the area-to-weight ratio is approximately 0.006 ft^2/lb, which results in a maximum longitudinal libration of less than 0.1 degree.

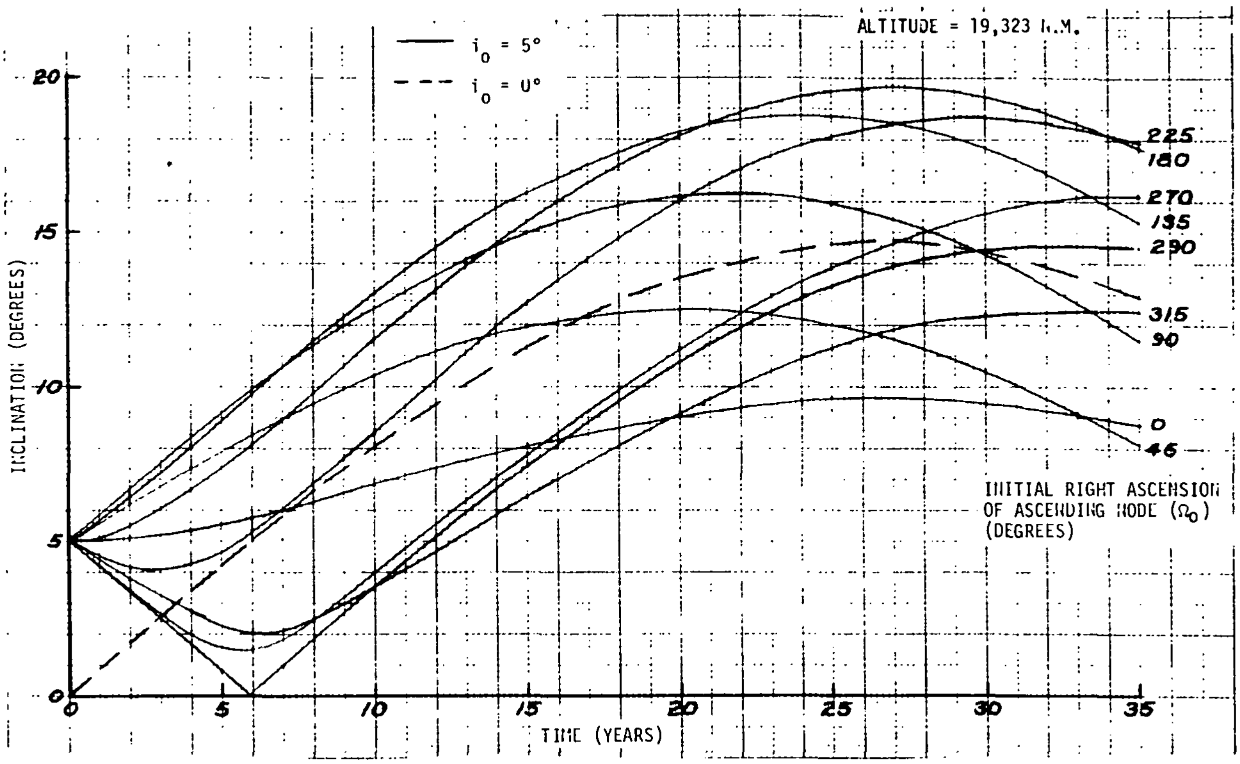


Figure 3-11. Mean Geosynchronous Luni-Solar Perturbation Effects

ELECTROMAGNETIC SPECTRUM UTILIZATION

Utilization of the electromagnetic frequency spectrum as the communication link between earth and geosynchronous satellites is limited by many factors, such as frequency allocations, atmospheric and environmental effects, and technology availability. This section of the report defines these factors and their effect on spectrum utilization. Improvement of spectrum utilization can be obtained by modulation and spatial-discrimination techniques that allow multiple use of the same frequency bands. These techniques are outlined, and their limitations are discussed. The data are developed into a format that is useful to planners of geosynchronous missions. Frequency bands may be selected and systems conceived that will support geosynchronous missions within the limitations defined.

Spectrum Allocations

The first set of data presented depicts the total range of the frequency spectrum from low frequency (LF, 100 kHz) through the gamma ray region to 10^{20} Hz. A series of eight charts (refer to Volume III) was developed to show world-wide frequency allocations for various services and specific propogation characteristics. To date, no frequency allocations have been made above 275 GHz.

Specific frequency allocations for space services were tabulated, including all frequency allocations established for world-wide use by the World Administrative Radio Conference in mid-1971. These allocations became effective as of January 1973. A summary of these allocations for fixed satellite and inter-satellite service is shown in Table 3-1. Of particular interest to this study are the fixed satellite service allocations usable for data relay-type missions. Data relay missions are the most extensive users of the available frequency spectrum.

Transmission Phenomena

Higher frequency bands are needed to support the large quantities of data (and, therefore, bandwidth usage) forecast during the time period of interest to this study. Presently, C-band (3.7 - 4.2 GHz downlink, 5.9 - 6.4 GHz uplink) is being utilized for data relay missions. To support the presently projected requirement, frequency bands above 10 GHz will be needed. Although these bands allow much greater data link capacity, atmospheric effects are more severe and must be carefully considered to provide high-quality communications. Data were compiled defining the atmospheric attenuation effects and identifying the atmospheric windows.

Weather effects are more severe as the operational frequencies increase above 7 to 8 GHz. Geosynchronous missions must account for increased signal margins in the communication links to ensure reliable signals during bad weather periods. Above 12 GHz, these margins approach 15 to 30 dB. A series of charts was constructed to define variations in signal attenuation with frequency and rain levels. Statistical rainfall data for different geographic areas were included to provide an indication of the likelihood of encountering adverse conditions. These data are useful in conducting link operational assurance/reliability studies. Also included were data illustrating the advantage of ground station geographical diversity under bad weather conditions.

Available Technology

Technology limitations were postulated for the upper ranges of allocated frequencies. State of the art of microwave and millimeter-wave hardware, and the limitation in providing space-proven equipment with the necessary performance, will constrain the use of frequencies during the 1990 time period to approximately 30 GHz. As shown in Table 3-2, this capability is sufficient to support the 1985-1990 projected traffic. Use of the 11/14 GHz and 20/30 GHz bands for data relay functions increases the usable bandwidth by a factor of eight over the presently used C-band (4/6 GHz). With the addition of feasible and proven techniques for "frequency reuse", the data rate per degree longitude of orbital space will approach 10×10^9 bps. This compares favorably to the 1.5×10^9 bps per degree projected for the new traffic model. Use of multi-beam spacecraft antenna systems, orthogonal polarization RF propogation, narrow beamwidth ground antennas, and multiple access modulation techniques allows simultaneous frequency operation up to six times at the highest frequency band, 20/30 GHz.

Table 3-1. WARC-ST Allocations Above 10 GHz

Frequency Band (GHz)	Link		
	Bandwidth	Space to Earth	Earth to Space
Fixed Satellite Service	(MHz)		
2.5 to 2.535	35	2, 3	
2.655 to 2.690	35		2, 3
	(GHz)		
3.7 to 4.2	0.5	X	
5.925 to 6.425	0.5		X
7.25 to 7.75	0.5	X	
7.90 to 8.40	0.5		X
10.95 to 11.2/11.45 to 11.7	0.5	X	
11.7 to 12.2	0.5	2*	
12.5 to 12.75	0.25	1, 3*	1, 2
14.0 to 14.5	0.5		X
40.0 to 41.0	1.0	X	
50.0 to 51.0	1.0		X
92.0 to 95.0	3.0		X
102.0 to 105.0	3.0	X	
140.0 to 142.0	2.0		X
150.0 to 152.0	2.0	X	
220.0 to 230.0	10.0		
265.0 to 275.0	10.0		
Inter-Satellite Service			
54.25 to 58.2/59.0 to 64.0	8.95		
105.0 to 130.0	25.0		
170.0 to 182.0	12.0		
185.0 to 190.0	5.0		

*Indicates world region for this link. There are three regions defined in the WARC documents.

Table 3-2. Projection of Geosynchronous Orbit Data Rate Capability

Time	Frequency Band	Per Satellite Data Rate Capability (bps)	Frequency Reuse	Spacing (deg.)	Data Rate per Degree (bps)
1975-1980	C	960×10^6	2 x	4.6	205×10^6
1980-1990	plus K_{LO}	2.88×10^9	2 x C 4 x K_{LO}	4.6	626×10^6
	plus K_{HI}	43.2×10^9	2 x C 4 x K_{LO} 6 x K_{HI}	4.5	9.82×10^9
	WORLD RATE* = $9.82 \times 10^9 \times 360 = 3.5 \times 10^{12}$ bps				
*capability of three-band usage as defined					

These frequency reuse techniques and their limitations were briefly investigated. Multiple-beam radiation techniques were limited to pointing separations of approximately two or three beamwidths. Orthogonal polarization radiation was found to provide up to 30 dB isolation between radiated signals, thus allowing double use of the frequency. Ground antenna discrimination by use of narrow beamwidth antennas will allow closely spaced satellites operating on the same frequency. Such operation provides the greatest potential for frequency reuse.

Figure 3-12 illustrates the orbital spacing that can be accommodated with different size ground station antennas. This data was generated for C-band operation to illustrate antenna sizes necessary to remain within the allowable CCIR limits of inter-satellite interference. The interference model was based on an eleven-satellite cluster equally spaced. Examination shows that a 60-foot ground antenna would allow a spacing of 4.6 degrees between satellites at C-band. Spacing could be closer for the higher frequencies (K_{LO} - 11/14 GHz and K_{HI} - 17/30 GHz) with feasible ground antenna sizes (30-foot diameter). The total data transfer capability via geosynchronous operations could, therefore, be even greater than indicated in Table 3-2, with the use of the higher frequency bands and spacing closer than 4.6 degrees. Thus, it is technologically feasible to support the traffic requirements projected through the 1990 time period using available frequencies below 31 GHz.

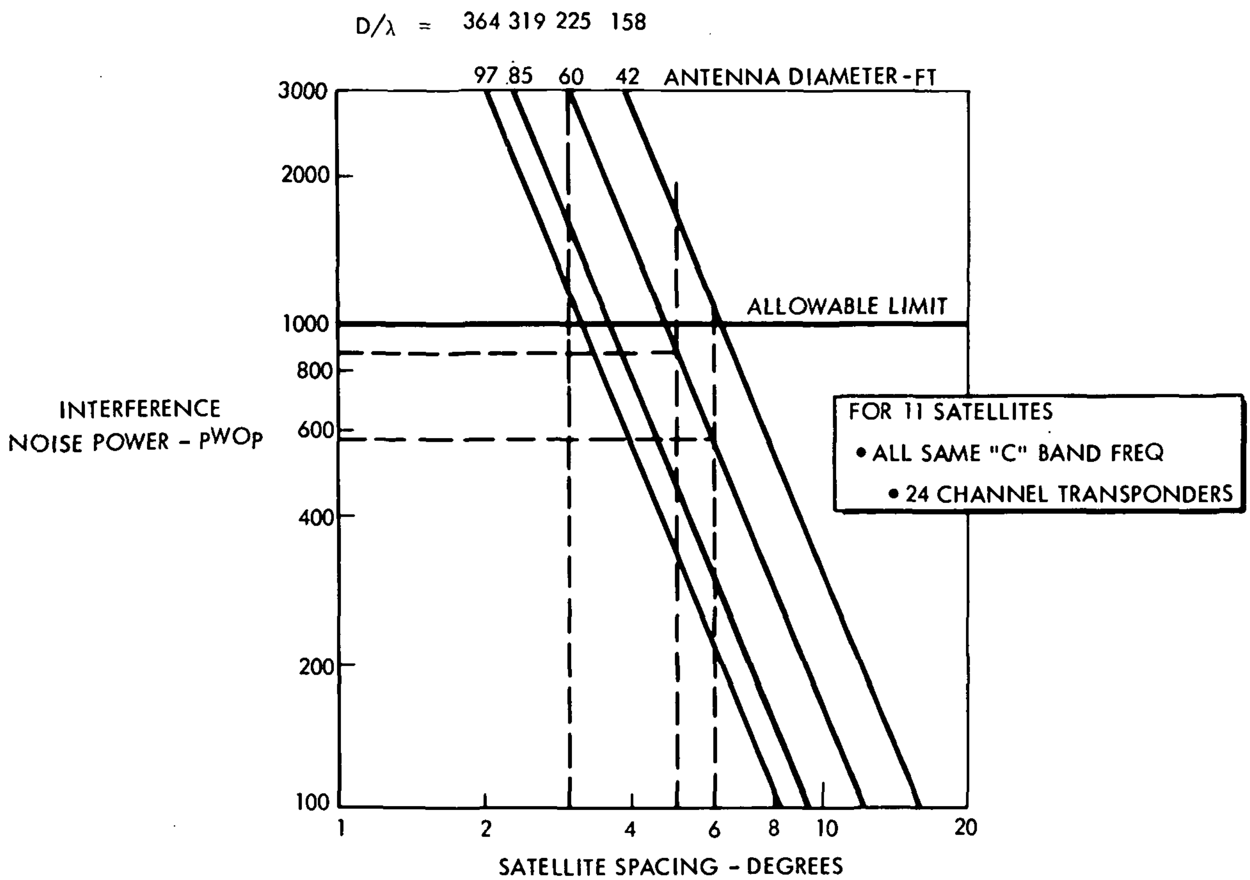


Figure 3-12. Interference Noise Versus Satellite Spacing

4.0 GEOSYNCHRONOUS TRAFFIC DEFINITION

Two different geosynchronous traffic models were constructed for use in the study. The first, called the baseline traffic model, was derived from currently planned geosynchronous missions. It was structured from mission planning and source material widely familiar to the NASA and the total aerospace community and thus provides a convenient comparison and traceability of study results to other past and on-going industry activities. The second model, the new traffic model, was derived by a totally different approach. It was based on a "bottom-up" approach utilizing quantitative forecasts of user demand levels. Traffic is correlated to the utilitarian benefits it provides to mankind.

The new traffic model reflects the dynamic growth in satellite communications and other space applications which are just beginning to emerge. It is intended to represent the full potential for geosynchronous traffic through the 1990 time period. Both of these traffic models form the basis for defining the nature, numbers, and schedules of geosynchronous mission activities which are utilized as basic study tools providing key input data to other study tasks. The new model defines the time-phased distribution of satellites necessary for assessment of orbit saturation conditions; geosynchronous functions and mission schedules are defined for use in functional grouping analyses and the determination of platform requirements; geosynchronous program objectives and capability levels are established for use in developing alternate program approaches.

BASELINE TRAFFIC

The construction of the baseline traffic model was centered around the compilation and review of related mission planning and systems definition data. Descriptive mission material from all sources were reviewed and correlated in order to group pertinent data into specific mission/functional categories. The principal source for the baseline traffic definition was the "Updated NASA Mission Model" (6 June 1972) in Reference 4-1. This model identifies the currently envisioned space missions from 1973 through 1990 for seven basic categories as listed below:

1. Astronomy
2. Space physics
3. Earth observations
4. Earth and ocean physics
5. Communications and navigation
6. Life science
7. Space technology and materials science

However, the model did not explicity identify those spacecraft which would be expected to operate in geosynchronous orbit. It was necessary, therefore, to review additional data from the "Fleming" Model in Reference 4-2 and other mission planning and definition material from References 4-3, 4-4, and 4-5 to establish a final pattern of geosynchronous missions.

The original seven mission categories were changed to five. Categories 2, 6, and 7 were deleted as not appropriate to geosynchronous orbits. Their objectives could be more economically achieved through other, lower-altitude orbits. A "Non-NASA Operational Satellite" category was added to account for commercial communications and other non-developmental satellites. After these basic categories of geosynchronous missions were defined, specific delivery schedules were constructed for the individual satellite types in each category.

The fundamental schedule structure was derived from two principal sources (References 4-1 and 4-2), and additional information from other sources was utilized as necessary to fill in important missing elements. The resulting delivery schedule for the baseline traffic model is shown in Table 4-1 in three parts, each reflecting a different prime information source. Delivery schedules for satellites in the first four mission categories (Part A) were obtained directly from the NASA Mission Model (Reference 4-1). This covers all satellites in these categories for the entire period from 1973 through 1990. However, the NASA Mission Model did not treat the expected non-NASA operational missions (fifth category) for which the NASA would provide launch support. To fill this void, the non-NASA operational spacecraft schedules defined in the "Fleming" Mission Model (Reference 4-2) were utilized. This model covered only the time period from 1979 through 1990 (Part B). The remaining delivery schedules in the 1973 through 1978 time period (Part C) for the non-NASA operational spacecraft were obtained primarily from information available in the open literature.

As shown in Table 4-1, a total of 180 satellites was identified in the baseline traffic model, with the majority (118) being non-NASA operational spacecraft. Peak traffic densities, in terms of the number of deliveries per year, range from 14 to 16. The resultant average delivery rate for the 18-year period is 10 satellite deliveries per year.

To complete the definition of the baseline traffic model, the time-phased distributions of satellites were derived. Preferred placement criteria and location rationale for each satellite type were developed from the payload and mission descriptive material contained in References 4-3, 4-4, and 4-5. These criteria are based primarily on earth-viewing or line-of-sight access considerations. In general, the astronomy and NASA communications and navigation payloads are located such that direct communications and in some cases, viewing of the contiguous United States, is possible. The non-NASA operational spacecraft have, in general, a world-wide distribution with specific locations dependent upon access to each of the continental regions. These location criteria were applied to each satellite type, along with quantitative earth coverage data from Volume III to define bands of permissible locations. They are shown in Figure 4-1 and are discussed briefly below.

Many of the NASA programs require access to the contiguous United States for simpler data links and/or domestic data-gathering purposes. The programs include astronomy, earth observations, and some of the communications and navigation satellites. Satellite locations between 55 and 135 degrees west longitude satisfy these requirements.

Table 4-1. Baseline Traffic Model

PART "A" (NASA MISSION MODEL, JUNE 1972)

CATEGORY	TITLE	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	TOTAL	SUB-TOTAL	CUM TOTAL
		SCHEDULE (CALENDAR YEAR)																				
ASTRONOMY	EXPLORERS						1			1			1			1			1	5	5	5
EARTH OBSERVATIONS	SYNCHRONOUS EARTH OBSERV. SAT								1		1			1		1			1	5		
	SYNCHRONOUS METEOROLOGICAL SAT.	1				1				1	1									4		
	SYNC. EARTH OBSERV. SAT./PROTO																		1	1	10	15
EARTH AND OCEAN PHYSICS	GEOPAUSE							1	1											2	2	17
COMMUNICATIONS & NAVIGATION	APPLICATIONS TECHNOLOGY SATELLITE	1		1			1	1			1	1		1		1		1		9		
	COOPERATIVE APPLICATIONS SATELLITE			1			1													2		
	SMALL APPL. TECHNOLOGY SATELLITE				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15		
	TRACKING & DATA RELAY SATELLITE					1	2					3						3		9		
	DISASTER WARNING SATELLITE						1	1												2		
	SYSTEM TEST SATELLITE								1	1	1	1	1	1		1	1			8	45	62

CATEGORY	TITLE	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	TOTAL	SUB-TOTAL	CUM TOTAL
NON-NASA OPERATIONAL SPACECRAFT	COMMUNICATION SATELLITE	1		2	3		2	2	1	1		2	1	1			2	1		19		
	U.S. DOMESTIC COMMUNICATION		2	2		2	2	1	2	1	1	2	2	2	2	2	2	2	2	29		
	FOREIGN DOMESTIC COMMUNICATION	4	1		1	2	3		2	6	2	2			4	5	2	1	2	37		
	NAVIGATION AND TRAFFIC CONTROL	1				1	2		1	1		1		1		1		1		10		
	SYNCHRONOUS METEOROLOGICAL			2		1		1	1	1	1	1	1	1	1	1	1	1	1	15		
	SYNCHRONOUS EARTH RESOURCES													4			4			8	118	180

PART "C" (OPEN LITERATURE)

PART "B" (FLEMING MODEL, OCTOBER 1971)

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ASTRONOMY	EXPLORERS	• DIRECT U.S. COMMUNICATIONS
EARTH OBSERVATIONS	SYNCHRONOUS EARTH OBSERVATION SATELLITE	• U.S. VIEWING • DIRECT U.S. COMMUNICATIONS
	SYNCHRONOUS METEOROLOGICAL SATELLITE	• OBSERVATION OF U.S. WEATHER SOURCES • DIRECT U.S. COMMUNICATIONS
	SYNCHRONOUS EARTH OBSERVATION SATELLITE/PROTOTYPE	• U.S. VIEWING • DIRECT U.S. COMMUNICATIONS
	GEOPAUSE	
COMMUNICATIONS & NAVIGATION	TRACKING AND DATA RELAY SATELLITE	• DIRECT COMMUNICATIONS WITH SINGLE U.S. GROUND SITE
	APPLICATIONS TECHNOLOGY SATELLITE	• MISSION OBJECTIVE DEPENDENT
	COOPERATIVE APPLICATIONS SATELLITE	• U.S./EUROPEAN COMMUNICATIONS
	SMALL APPL. TECHNOLOGY SATELLITE DISASTER WARNING SATELLITE SYSTEM TEST SATELLITE	• DIRECT U.S. COMMUNICATIONS
NON-NASA OPERATIONAL SPACECRAFT	COMMUNICATION SATELLITE	• WORLD-WIDE INTERCONTINENTAL COVERAGE
	U.S. DOMESTIC COMMUNICATION	• DIRECT INTRANATIONAL (U.S.) COMMUNICATIONS
	FOREIGN DOMESTIC COMMUNICATION	• DIRECT INTRANATIONAL COMMUNICATIONS
	NAVIGATION AND TRAFFIC CONTROL	• WORLD-WIDE COVERAGE OF MAJOR AIR TRAFFIC CORRIDORS
	SYNCHRONOUS METEOROLOGICAL	• WORLD-WIDE COVERAGE OF MAJOR WEATHER SOURCES
	SYNCHRONOUS EARTH RESOURCES	• WORLD WIDE COVERAGE

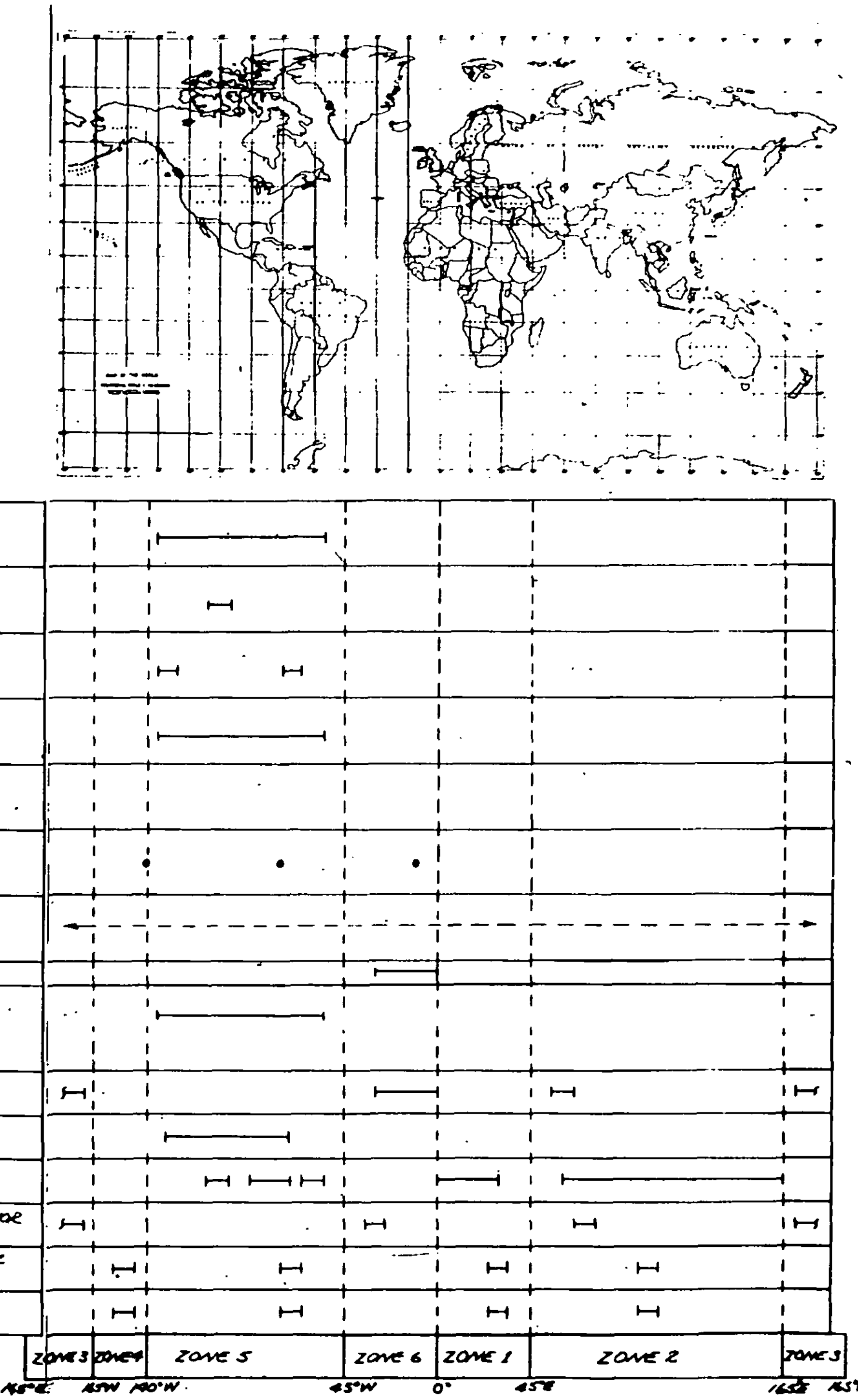


Figure 4-1. Preferred Geographic Locations

The NASA earth-observation and meteorological satellites were further constrained to 15-degree longitudinal bands specifically located as shown in Figure 4-1 to provide balanced, coast-to-coast viewing of the continental U.S. (from the standpoint of line-of-sight incidence) and to cover the Aleutian and Carribean weather cells which influence U.S. weather patterns.

The tracking and data relay satellites (TDRS) were located as specified in a recent Rockwell TDRS study (Reference 4-7). Two active satellites are placed such that direct communications with a single ground station is possible and an on-orbit spare is located midway between the two active satellites.

The applications technology satellite (ATS) locations are dependent upon mission objectives yet to be defined and thus are shown as a dashed line indicating potential placement anywhere.

The non-NASA satellite location bands followed similar patterns. The communications satellites were placed in three location bands centered over the Atlantic, Pacific, and Indian Oceans. These permit world-wide international communications between the major land masses. U.S. domestic communications is, of course, limited by access to the continental U.S., Hawaii, and Alaska. Foreign Domsat communications were located to provide coverage for Canada, Central and South America, Europe/Africa, and Asia. The non-NASA meteorological and earth resources satellites were configured to be sets of four equally spaced satellites that provide global surveillance capability. Their specific locations were the result of compromises between good viewing of weather patterns and low-incidence viewing of agricultural and other land mass regions.

Examination of the resulting overall pattern of distributions revealed that the functional coverage bands tended to be grouped into six separate zones. The criterion for defining these zones was simply that the coverage bands could not extend across the zonal boundaries. Six longitudes were found where this criteria was met. These zones are identified by vertical dashed lines in Figure 4-1. Zone 1 provides coverage of Europe and Africa. Coverage of Asia and Australia is provided by Zone 2. Zones 3, 4, and 6 provide coverage of the Pacific and Atlantic Oceans, while Zone 5 provides coverage of North and South America. Although there is some potential overlap in coverage between adjacent zones, the identified zones were found to be useful in constructing the time-phased distributions of satellite population histories.

Satellite population histories were determined for each of the six zones. Representative mission lifetimes for each type satellite were utilized in conjunction with the satellite delivery schedule in Table 4-1 to construct these population histories. Payload and mission descriptive material from References 4-3 through 4-7 was reviewed, along with inputs from the open literature on commercial communications satellite plans to establish mission life. Values ranged from one year for the small applications technology satellite to seven years for the commercial communications satellites. The most common lifetime values ranged from three to five years. Specific data are presented in Volume IV, Part 1.

The resulting active satellite populations are summarized in Figure 4-2. Population levels are shown for each satellite type along with the total population in each of the six zones defined above. Population construction details for each satellite type, including delivery year, period of active mission life, and location bands for each delivery, are shown in Volume IV, Part 1. Both active and inactive satellite populations are summarized.

NEW TRAFFIC MODEL

As indicated earlier, the construction of the new traffic model was based on a new and different approach. Briefly, it was a "bottom-up" approach which included: (1) the identification of geosynchronous mission objectives in terms of candidate user functions; (2) the formulation of U.S. user demand profiles for each function; (3) the extrapolation of U.S. demand profiles to world-wide models; and (4) the determination of the number of traffic units required in terms of equivalent satellites to those appearing in the baseline traffic model.

Candidate functions applicable to geosynchronous satellite systems are listed in Table 4-2 under three major categories. Communications and data functions are those which are applicable to international and domestic communications satellites. Science and applications functions are principally data-gathering operations supporting both terrestrial resource management and basic research. Also included are the major new functions of space power and light which offer vast benefits to mankind. National defense includes global communications and sensor functions necessary for national security. While gross estimates of DoD traffic were treated in the orbit saturation analyses, no attempt was made to analyze the grouping capability or integration of these payloads with other non-DoD functions in the definition of space platforms.

Detailed forecast models were constructed for each of the above functions. Current traffic levels and projected growth rates from major communications industry sources were utilized. Long-distance traffic was the principal base for these projections. However, further consideration was given to the ratio of satellite traffic to total long-distance traffic. The percent of the long-distance traffic projected to be handled via satellite ranged from 1.6 percent in 1970 to 30 percent in the year 2000. An example of the resulting forecast models is presented in Figure 4-3, which shows projected U.S. telephone use up to the year 2000. These data reflect both the expected growth in the basic telephone service and the introduction and growth of videophone service, which utilizes greater increments of data rates. More than an order of magnitude growth in satellite traffic is predicted by 1990. Specific models such as this were constructed for each of the communications functions. Together they compose a U.S. traffic model.

The U.S. traffic forecasts were extended to a world model by ratioing user populations. Census data and population growth rates were obtained for various world areas. These were refined to include only the literate populations greater than 14 years of age, which were considered to be the principal users of the communications functions. These were then ratioed to the U.S. population profile to produce the extrapolation factors for the world-wide communications

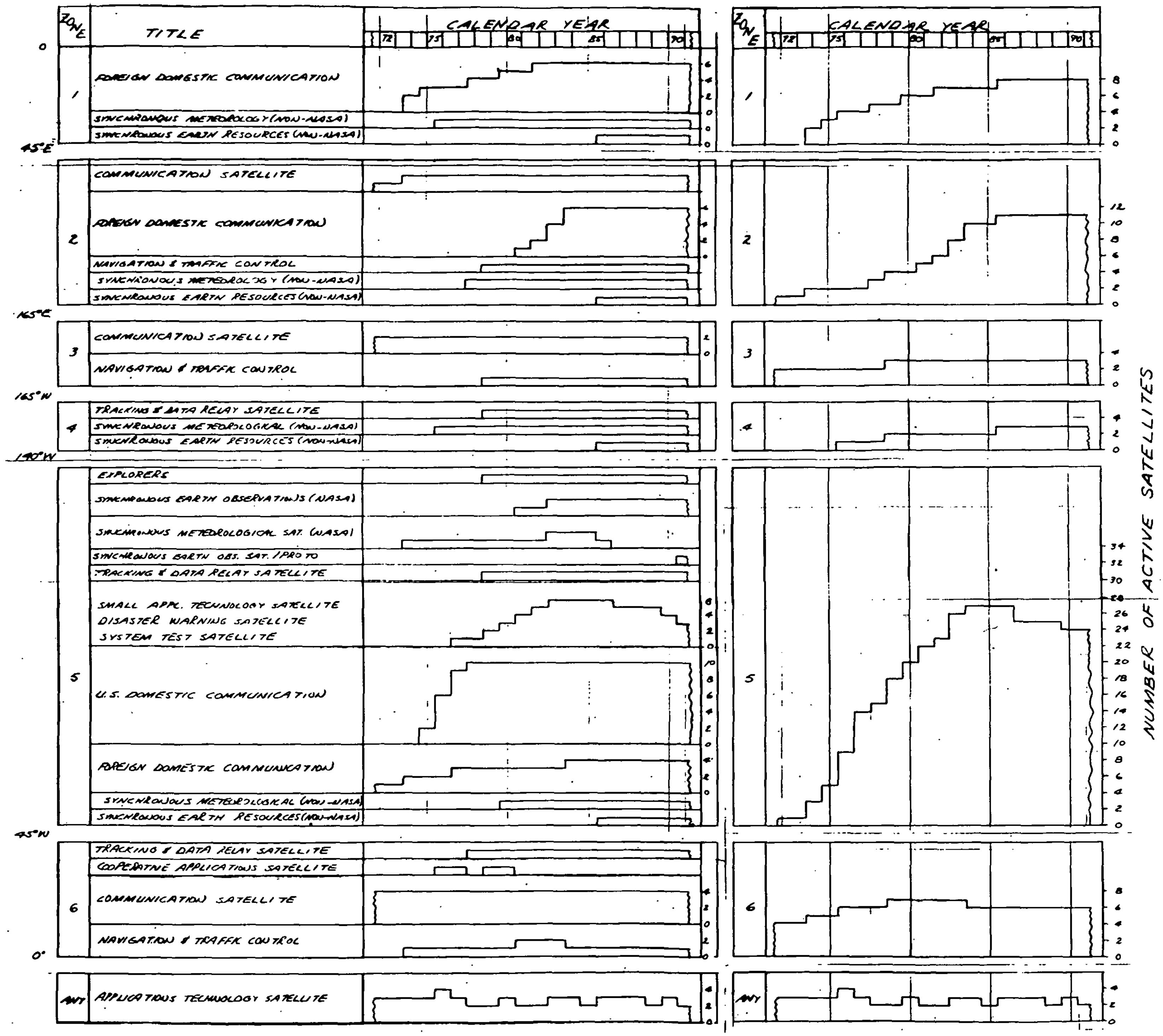


Figure 4-2. Active Satellite Population Distribution Summary

Table 4-2. Candidate Geosynchronous Functions

Communications and Data	Science and Applications
1. Education	1. Meteorology
2. Commercial broadcast	2. Earth resources
3. Teleconference	3. Navigation
4. Telegraph	4. Aircraft control
5. Post office	5. Communications and systems test
6. Medical data bank	6. Astronomy
7. Banking/business/credit trans	7. Tracking and data relay
8. Newspaper	8. Solar illumination
9. Electronic publishing	9. Space power relay
10. Civil defense	
11. Welfare data banks	
12. Library data banks	
13. Private record banks	
14. Telecomputations	
National Defense - communications and sensor data	

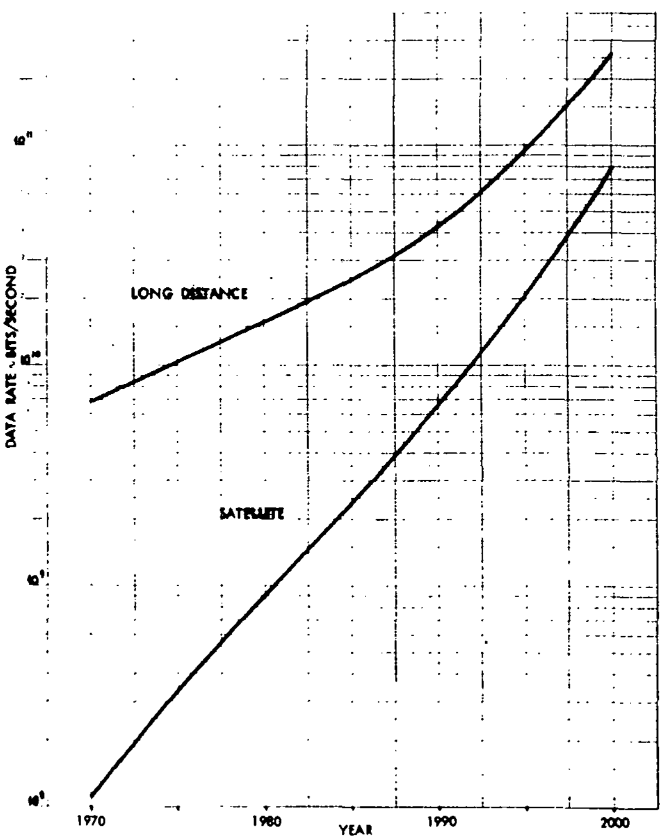


Figure 4-3. Teleconference Function Demand Model

functions shown in Figure 4-4. An example of the application of these factors is presented in Figure 4-5, which shows world domestic communications forecasts for major continental areas. In constructing this model, the data rate forecasts for individual functions were combined and adjusted to reflect only domestic communications traffic. A similar process was applied to the determination of international traffic levels.

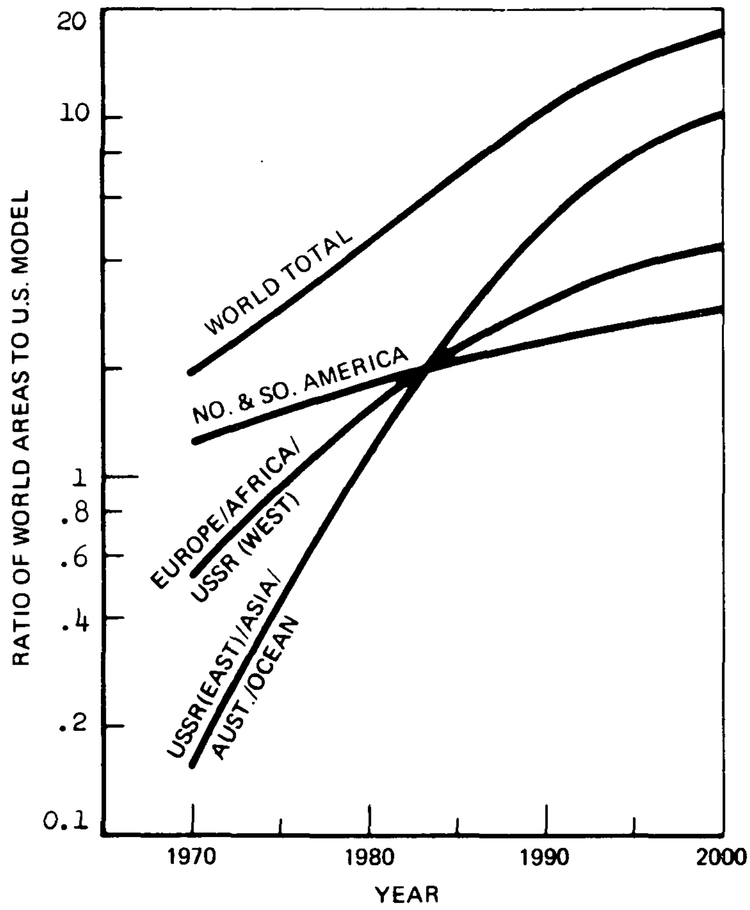


Figure 4-4. Extrapolation Ratios for Principal World Areas

World science and applications traffic levels were developed by comparing estimated space program budgets of the leading world powers to that of the United States. The USSR space activity in these functional categories was presumed comparable to U.S. levels. Japan, China, and European (consortium) program levels reflected growths relative to U.S. space activity during the projected time period. Values for Japan ranged from a current level of 3 percent to 10 percent in the year 2000. China and Europe were considered to have comparable programs, each ranging from 15 percent to 50 percent of U.S. levels over the same time period. These factors were applied to the U.S. science and application traffic (i.e., meteorology, earth observations, astronomy, etc.) to establish a world-wide model.

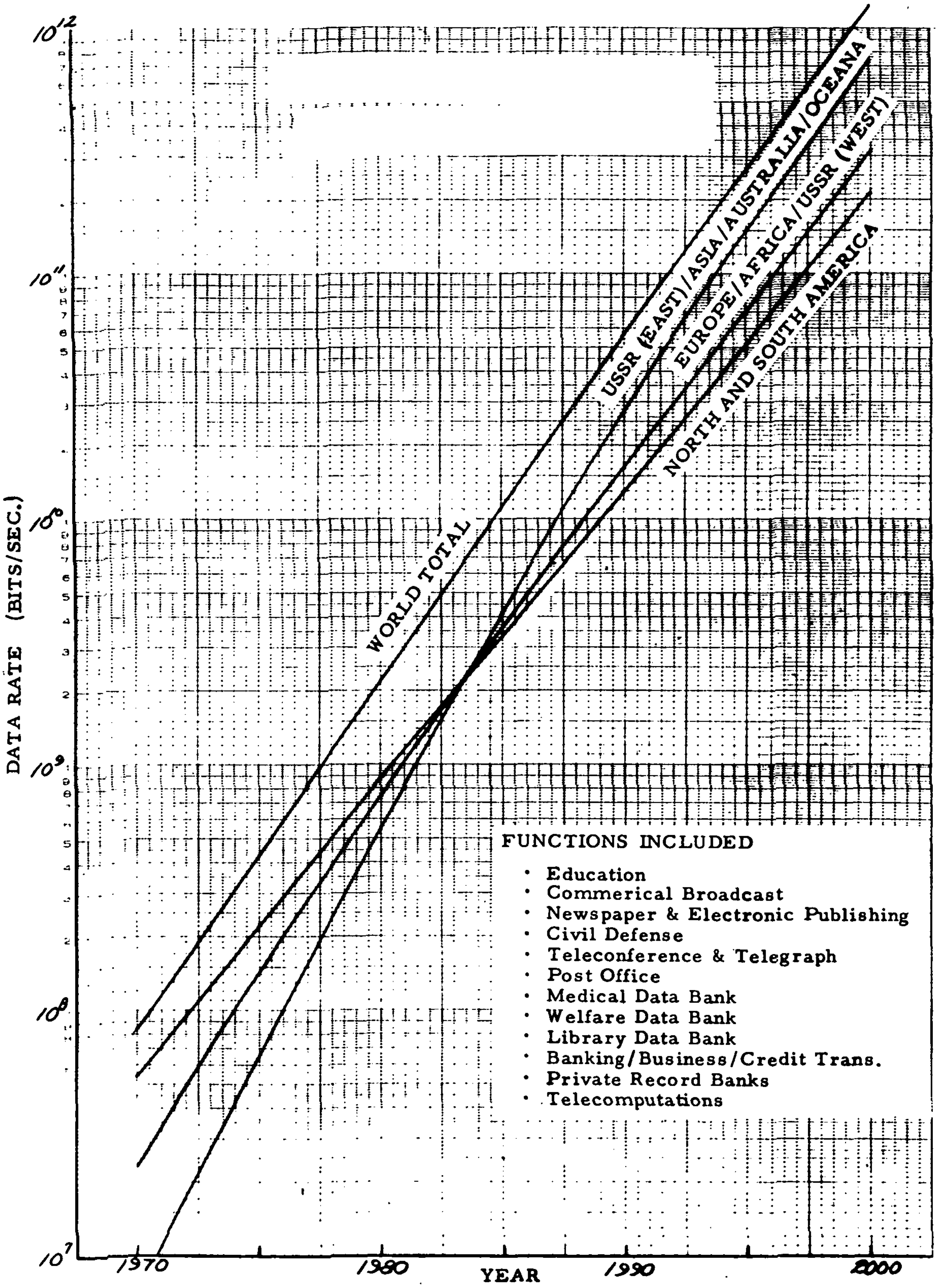


Figure 4-5. World Domsat Forecast Model
(By Continental Area)

For ease of comparison with the baseline traffic model, the data rate requirements and levels of other traffic parameters derived above were converted into the number of equivalent satellites. Functional capacities, mission life, and other pertinent characteristics matching those in the baseline model were used. The resulting new traffic model is summarized in Table 4-3. A total of 413 satellites is required compared to 180 in the baseline model.

Table 4-3. New Traffic Model Summary - Delivered Satellites by Area

SATELLITE TYPE	SCHEDULE (CALENDAR YEAR)																		TOTAL	SUB-TOTAL	CUM TOTAL
	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90			
INTELSAT																					
ATLANTIC OCEAN	1			1	1		1		1		2	1	1	2	1	2	1	3	18		
PACIFIC OCEAN	1			1		1		1		1	2	1	2	1	2	2	3	4	22		
INDIAN OCEAN		1			1		1	1		1	1	2	1	3	3	2	3	4	24		
SUBTOTAL	2	1	-	2	2	1	2	2	1	2	5	4	4	6	6	6	7	11		64	64
DOMSAT																					
NORTH AND SOUTH AMERICA	1		2	2	2	2	1	1		2	3	3	3	3	3	6	7	9	50		
EUROPE/AFRICA/USSR (W)			1		1		1		1	2	2	2	2	4	6	6	10	12	50		
USSR (E)/ASIA/AUSTRALIA					2	2	2			2	2	2	4	6	8	10	18	22	80		
SUBTOTAL	1	-	3	2	5	4	4	1	1	6	7	7	9	13	17	22	35	43		180	244
MERSAT	2	2	1	2	3	-	2	2	-	2	2	-	2	2	-	-	-	-	22	22	268
NACSAT	1	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	-	61	61	327
ATS																					
UNITED STATES		1	1	1		1	1		1	1		1	1		1	1		1	12		
FOREIGN		2	1	2		1	2	2	1	1		2	2		1	1	3	1	22		
SUBTOTAL	-	3	2	3	-	2	3	2	2	2	-	3	3	-	2	2	3	2		34	361
ASTRONOMY																					
UNITED STATES						1		1		1		1		1		1		1	7		
FOREIGN								2		1		2		1		2		2	10		
SUBTOTAL	-	-	-	-	-	1	-	3	-	2	-	3	-	2	-	3	-	3		17	378
TDRS																					
UNITED STATES						2	1				2	2				2	2		11		
FOREIGN						2	1	1	1	1	4	3	1	1	1	4	3	1	24		
SUBTOTAL	-	-	-	-	-	4	2	1	1	1	6	5	1	1	1	6	5	1		35	413
ANNUAL TOTAL	6	6	10	13	14	16	17	15	9	19	24	26	23	28	30	43	54	60			

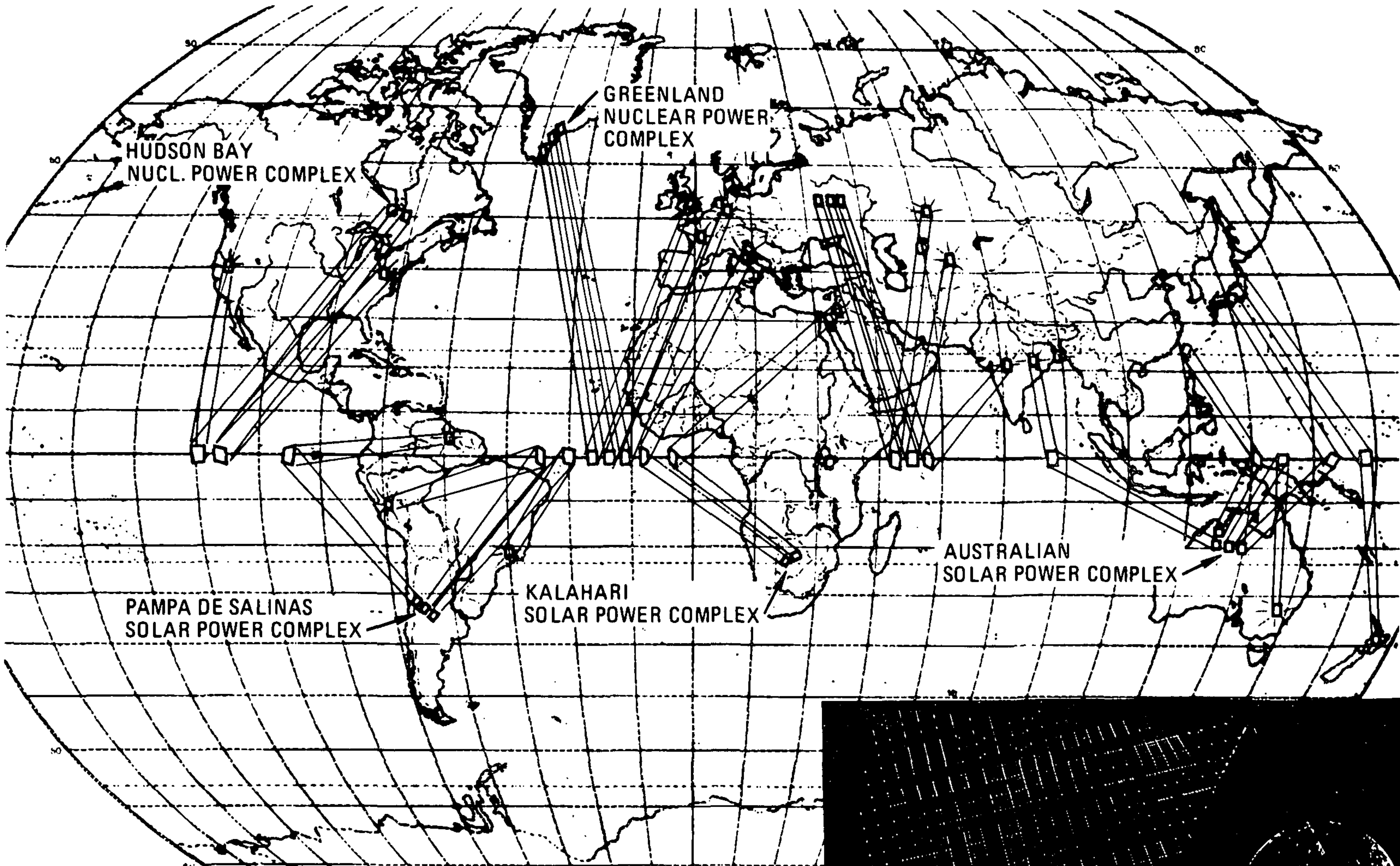
The same satellite location criteria utilized to construct the satellite distributions for the baseline traffic were applied to the satellite population in the new model. The resultant distributions by year for each of the six zones are shown in Table 4-4. Also included are the number of inactive satellites remaining on-orbit if all those whose active mission life expires after the reusable tug becomes available (1982) are retrieved. If no satellites are retrieved and allowances are made for the pre-1973 population and projected estimates of DoD traffic, the total 1990 on-orbit population will become 499 satellites.

These traffic models provided the satellite distributions for the orbit saturation analyses and were the basis for establishing the time-phased mission and program requirements for geosynchronous operations which were utilized in the functional grouping analysis and platform requirements derivations. In

Table 4-4. Satellite Distributions for the New Traffic Model

ZONE	MODE	SCHEDULE (CALENDAR YEAR)																	
		73		75					80					85					90
1 0-45°E	ACTIVE	4	5	6	6	8	6	6	7	8	9	11	13	15	18	24	29	37	47
	INACTIVE		1	2	3	4	7	9	10	11	13	13	13	13	13	13	13	13	13
	TOTAL ON-ORBIT	4	6	8	9	12	13	15	17	19	22	24	26	28	31	37	42	50	60
2 45°E-165°E	ACTIVE	1	3	4	5	7	11	17	19	19	23	27	30	33	39	49	61	80	103
	INACTIVE	1	1	1	1	3	3	5	8	8	8	8	8	9	9	9	9	9	9
	TOTAL ON-ORBIT	2	4	5	6	10	14	22	27	27	31	35	38	42	48	58	70	89	112
3 165°E-165°W	ACTIVE					2	5	5	5	5	5	5	6	6	6	6	6	6	6
	INACTIVE																		
	TOTAL ON-ORBIT					2	5	5	5	5	5	5	6	6	6	6	6	6	6
4 140°W-165°W	ACTIVE	3	3	3	3	3	4	4	5	5	6	8	9	10	11	12	14	16	18
	INACTIVE	2	2	2	4	4	5	6	6	6	6	6	6	6	6	6	6	6	6
	TOTAL ON-ORBIT	5	5	5	7	7	9	10	11	11	12	14	15	16	17	18	20	22	24
5 45°W-140°W	ACTIVE	5	5	7	13	17	20	20	21	21	20	22	24	25	27	29	35	40	46
	INACTIVE	1	2	3	4	4	5	9	10	15	18	18	17	17	17	17	17	17	17
	TOTAL ON-ORBIT	6	7	10	17	31	25	29	31	36	38	40	41	42	44	46	52	57	63
6 0-45°W	ACTIVE	3	4	8	9	9	9	11	12	13	13	12	12	13	14	15	15	17	19
	INACTIVE	6	6	6	7	8	10	10	14	15	15	16	16	16	16	16	16	16	16
	TOTAL ON ORBIT	9	10	14	16	17	19	21	26	28	28	28	28	29	30	31	31	33	35
1-6	ACTIVE	16	20	28	36	46	55	63	69	71	76	85	94	102	115	135	160	196	239
	INACTIVE	10	12	14	19	23	30	39	48	55	60	61	60	61	61	61	61	61	61
	TOTAL ON-ORBIT	26	32	42	55	69	85	102	117	126	136	146	154	163	176	196	221	257	300
		73		75					80					85					90

addition, advanced concepts for space power and light were identified, but they were considered to be beyond the 1990 period of study interest and thus were not included in the detailed traffic analyses. An example of these concepts is presented in Figure 4-6, which shows a geosynchronous energy relay system. Terrestrial power generators, favorably located for energy source and/or away from already polluted population centers, are depicted beaming their power via a geosynchronous relay station to the major industralized areas of need. Since solar and geothermal power sources could be utilized with this concept, the burden of chemical fuel sources and the amount of combustion pollutants would be reduced. Nuclear power sources could be remotely located for safety and for utilizing the vast heat sink capacity of the colder, higher latitude regions. Although these concepts require very large space installations with attendant needs for advanced, economical space transportation, the potential benefits they offer to mankind are enormous.



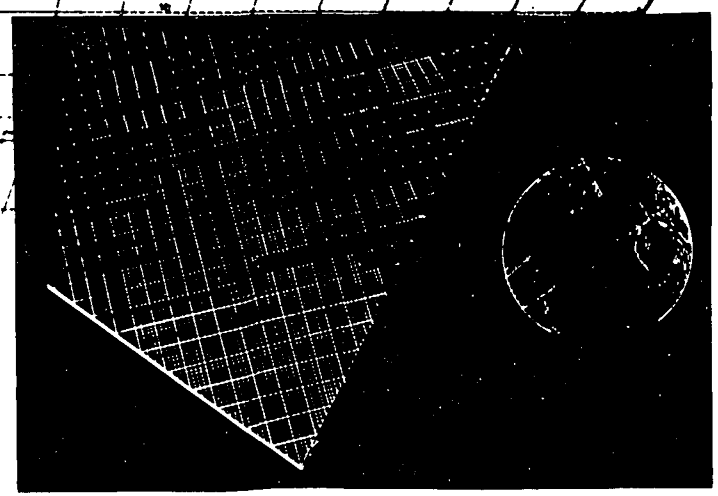


Figure 4-6. Geosynchronous Energy Relay System

5.0 ORBIT SATURATION ANALYSIS

The preceding traffic models were analyzed to determine the nature and degree of satellite congestion likely to occur in geosynchronous orbit if the current approach of launching individual payloads is continued through the 1990 time period. The objective of this effort was to determine whether satellite interference is likely to reach levels sufficiently high that a need for multifunction platforms is created purely on a technological basis. Other portions of the study (Volume VI) treat the economic and logistics advantages of grouping payloads into space platforms. The orbit saturation analysis included satellite physical contention and electromagnetic interference (EMI) for both active and inactive satellite populations.

ACTIVE SATELLITE CONGESTION

For the active satellite populations, it was determined that east-west stationkeeping capability was the dominant factor influencing the allowable physical spacing between satellites. All satellites placed in geosynchronous orbit utilize east-west stationkeeping to offset the effects of the tesseral harmonic perturbations. Without stationkeeping, these perturbations would produce long-period (2 to 8 years), cyclic, east-west motions carrying the satellites many thousands of miles away from their intended operating locations. In addition to these effects, luni-solar perturbations cause a slow orbit inclination drift (approximately 0.9 degree per year) and a nodal precession rate of -6.8 degrees per year from an initial nodal position near the vernal equinox. Orbit inclination produces a figure-eight ground trace pattern with north-south latitude excursions equal to the inclination; i.e., an inclination of one degree produces latitude excursions of ±1.0 degree. Nodal precession affects the phase relationship of the satellites within their figure-eight patterns (their location within the figure-eight pattern as a function of time of day). Neither of these effects poses a serious problem for geosynchronous satellites in meeting their earth coverage requirements. Thus, none of the satellites in the two traffic models defined for this study include north-south stationkeeping maneuvers to control these perturbations.

The orbit trends of geosynchronous satellites are illustrated in Figure 5-1. A sequence of three adjacent satellites launched one year apart is depicted. All are presumed to perform east-west stationkeeping within their respective "deadbands" which are shown as shaded bars in the figure. The orbit inclination increase with time is also shown along with its effect on the figure eight ground-trace patterns. Since the nodal separation between the adjacent satellites is small (6.8 degrees), the relative phase relationships are synchronized to nearly the same time. The satellites nearly parallel each other around their figure-eight pattern, maintaining approximately the same lateral spacing as at the equatorial crossings. Thus, the allowable physical spacing is principally governed by east-west stationkeeping and related tolerances. Typical current stationkeeping deadbands range between ±0.1 and

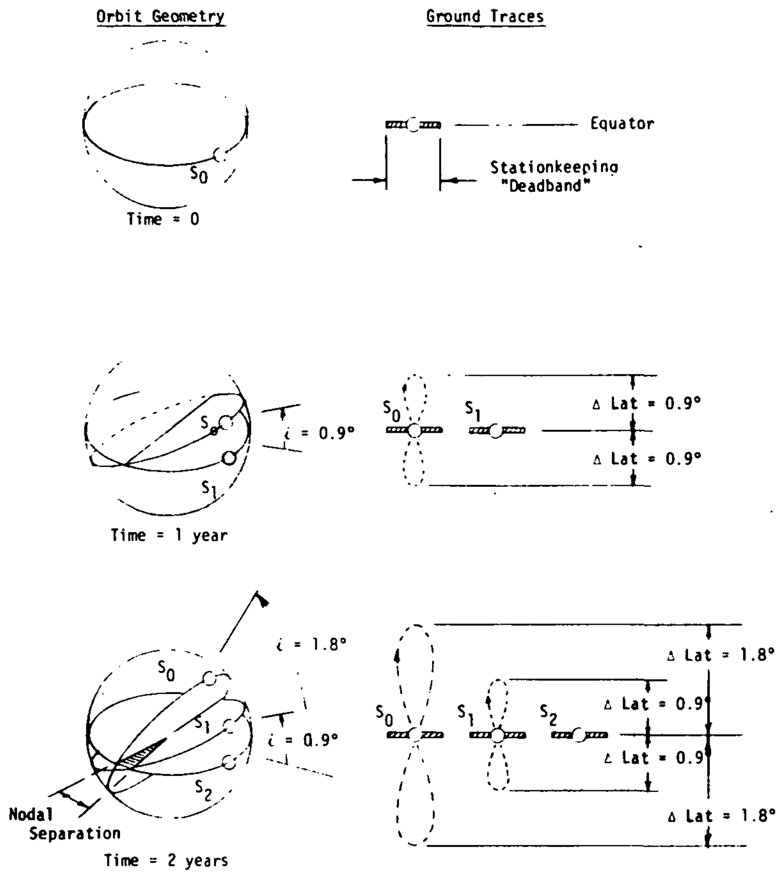


Figure 5-1. Geosynchronous Orbit Trends for Active Satellites

±0.15 degree. Applying a 50 percent margin to an average of these values produces an allowable safe spacing criteria of 0.40 degree longitude between adjacent satellites. This value was utilized to assess the degree of physical contention existing within the satellite distributions projected for the traffic models in this study.

In addition to physical spacing considerations, the active satellite populations were investigated for potential EM interference. A survey of the baseline and new traffic models shows the most populous satellite type, with the highest local satellite concentration to be the communications relays which operate in the 3.7 to 6.4 GHz, C-band frequencies. To analyze the interference potential for these satellites, a simplified but conservative model was constructed. A system of eleven uniformly spaced statellites, all with the respective RF characteristics shown in Table 5-1, was postulated. These produce a pattern of wanted and unwanted signal paths such as that depicted in Figure 5-2. The contributions from all unwanted signal paths were combined into a total noise power value. Satellite spacing and ground antenna diameter were varied parametrically to determine their effects on total noise power. The resulting parametric relationships are presented in Figure 5-3.

Table 5-1. Domsat Characteristics

MISSION/FUNCTIONAL GROUPING: Domsat - 1975		
	Operating Frequency	
	3.7 to 4.2 GHz	5.9 to 6.4 GHz
SATELLITE	DOWNLINK	UPLINK
Antenna gain (dB)	30.0	33.5
Antenna field of view (degrees)	2.5 x 6.0	2.5 x 6.0
Antenna polarization	Alternate orthogonal	Alternate orthogonal
System noise (degrees K)	--	1480
Rec. G/T (dB/degrees K)	--	1.9
Trans. output power (dBw)	6.0	--
EIRP (dBw)	36.0	--
GROUND STATION		
Antenna gain (dB)	54.0	58.7
Antenna field of view (degrees)	.34	.19
System noise (degrees K)	123.0	--
Rec. G/T (dB/degrees K)	33.0	--
Trans. output power (dBw)	--	28.0
EIRP	--	84.0
SYSTEM		
Bandwidth	500	500
Modulation	FM	FM
Geography	CONUS	

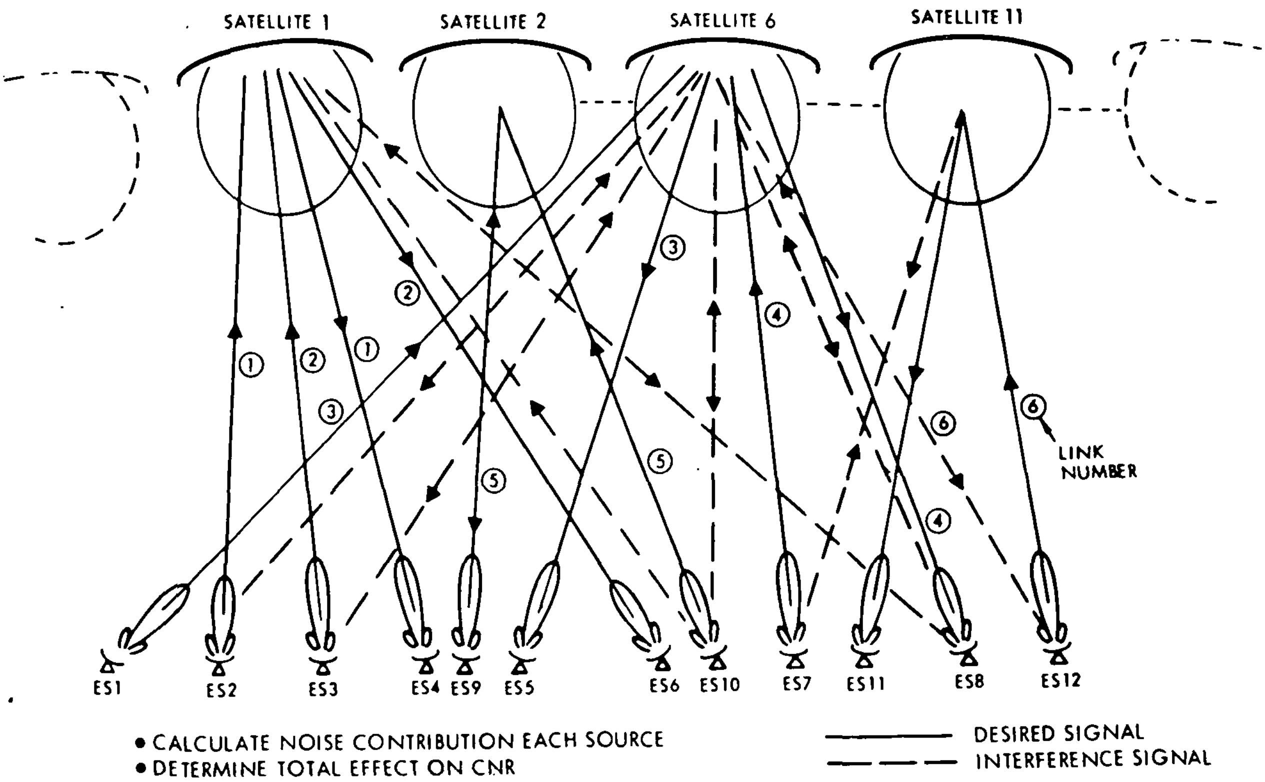


Figure 5-2. Interference Modes/Shared Frequency Operation

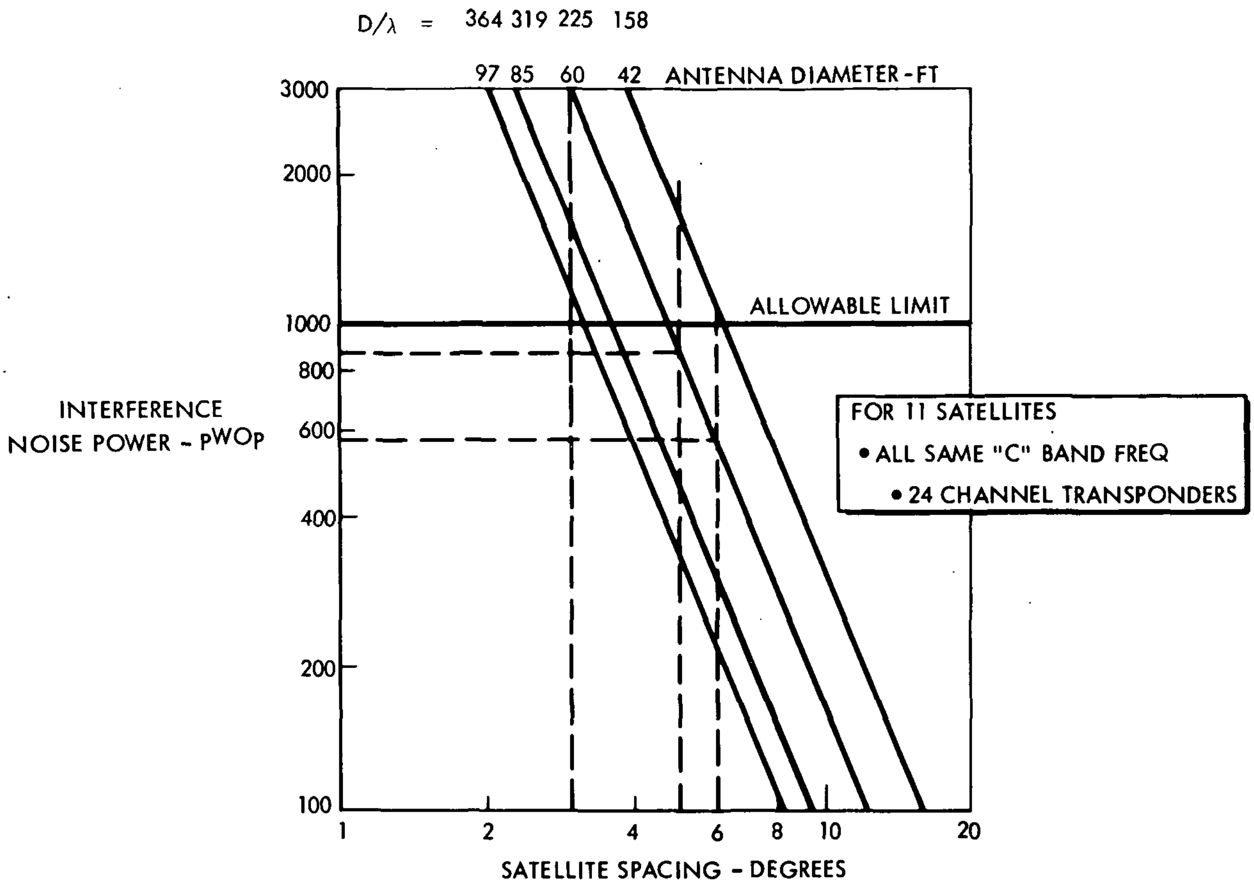


Figure 5-3. Interference Noise Versus Satellite Spacing

Acceptable values of satellite spacing were determined by applying the CCIR (Consultative Committee on International Radio) noise power limits of 1000 picowatts (psophometrically weighted). For the 60-foot diameter ground antennas currently being considered for domestic communications systems, satellites could be safely operated with a minimum spacing of 4.6 degrees longitude. Use of larger, 97-foot ground antennas would reduce this spacing requirement to approximately 3.0 degrees. Thus, EMI contention poses a more serious constraint to geosynchronous operations than physical proximity. It requires 4.6-degree spacing compared to 0.4 degree required for physical spacing.

To evaluate the nature and degree of physical and EMI contention which could exist within the active satellite populations, additional satellite characteristics were defined and detailed distributions were established for each satellite type. An example of these distributions is presented in Figure 5-4 which shows individual satellite locations and pertinent coverage bands for 1990 traffic in the new traffic model. Satellites operating in different frequency bands were interspersed in such a way as to maximize the spacing between satellites operating at the same frequency. In each case, the placement of a satellite was in conformance with the earth coverage

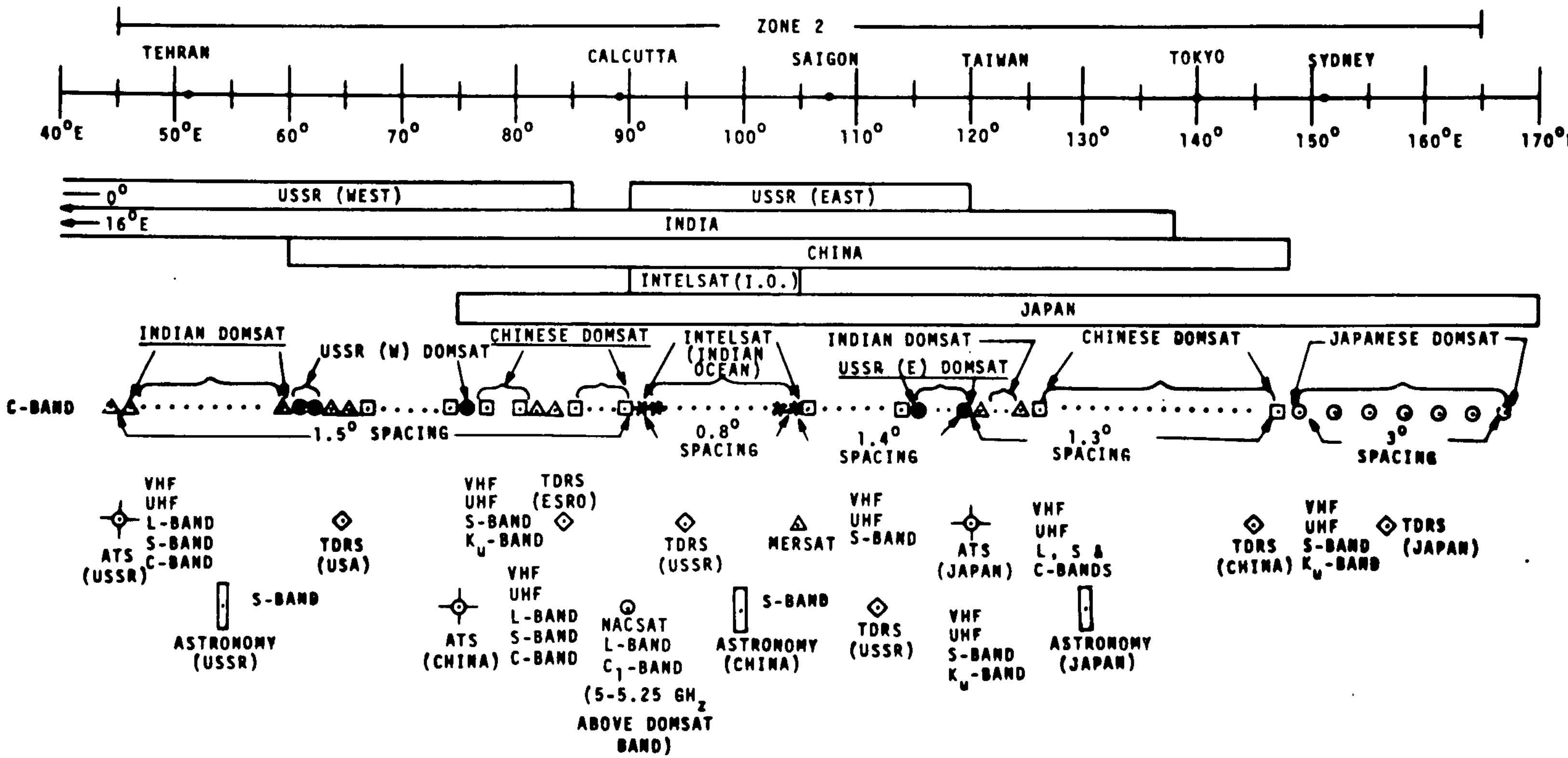


Figure 5-4. 1990 Satellite Distribution for the New Traffic Model

requirements specified for its particular mission or function. This procedure resulted in the widest spacing possible for potentially interfering satellites. However, closer physical spacing was induced between some configurations of differing bands than simple uniform distributions of all satellites within their respective coverage bands.

The resulting satellite spacing characteristics are summarized by zone in Tables 5-2 and 5-3 for the baseline and new traffic models, respectively. Nowhere was the physical spacing criteria of 0.4 degree violated, even for the high traffic levels predicted by 1990 in the new model. However, in all six zones the high traffic levels in the new model severely violated the 4.6-degree , C-band EMI spacing criteria defined above. Even the least crowded zones, 3 and 4, required 2.4 degrees spacing to fit all of the satellites within their coverage constraints. This exceeds the EMI spacing criteria by a factor of nearly two. Other zones were even more critical.

Table 5-2. 1990 Satellite Spacing for the Baseline Traffic Model

Traffic Type	Zonal Spacings (degrees)					
	1	2	3	4	5	6
C-band communications relay satellites	7.5	15	15	No C-band sat.	6	11
S-band satellites	7.5	11	No S-band sat.	8	5.4	30
Overall physical proximity	3.8	5	10	6	3	3

Table 5-3. 1990 Satellite Spacing for the New Traffic Model

Traffic Type	Zonal Spacings (degrees)					
	1	2	3	4	5	6
C-band communications relay satellites	1.5	0.8	2.4	2.4	2.0	1.7
S-band satellites	5.0	5.0	9.5	10.0	8.5	10.1
Overall physical proximity	0.75	0.4	1.2	1.2	1.0	0.85

S-band traffic was sufficiently dispersed in both models that no interference between geosynchronous S-band satellites was predicted. It was determined, however, that S-band interference between geosynchronous satellites and satellites in other orbits is likely, and would pose a problem in both traffic models. This was confirmed in discussions with SAMSO representatives on DoD plans for geosynchronous operations. S-band is used by both the NASA and DoD in their STDN and SGLS networks for operation of deep-space and low-earth orbit missions as well as geosynchronous operations. Although the scope of this study was limited to geosynchronous missions, the geometric interrelationships with S-band users in other orbits were recognized as sources of intermittent interference. Coordination and cooperation between the NASA and DoD will be required in both the planning and "real-time" control of these missions.

INACTIVE SATELLITE CONGESTION

Since all satellites in geosynchronous orbits must employ east-west stationkeeping to control the effects of tesseral harmonic perturbations, once they become inactive (either through failure or depletion of mission consumables) and are without stationkeeping capability, they drift freely and are subject to perturbing influences which totally dictate their orbital motion. Thus, orbit perturbations become the dominant factor in assessing potential physical contention among the inactive satellite populations.

The orbit perturbation effects interact to produce small altitude deviations, particularly the tesseral harmonics and solar pressure. This, coupled with the inclination excursions and nodal regression, results in a total "swept volume" of space approaching 3×10^{10} nm^3. This is illustrated by the shaded region in Figure 5-5. When the entire population of geosynchronous satellites projected to exist through the 1990 time period is applied to this volume, extremely large average volumes per satellite results. Total populations, including estimated foreign and DoD satellites, are 295 and 499 for the baseline and new traffic models, respectively. (These conservative figures include both active and inactive satellites.) Average volumes occupied per satellite range from 60×10^6 nm^3 to 100×10^6 nm^3 for the new and baseline traffic models, respectively. These enormous volumes reduce the possibility of collision hazards to negligible levels.

While average volume would be a true indication of collision probability only for purely random comditions, it is felt to provide a strong indicator in this case, particularly in light of the magnitude involved. The year of initial satellite placement, the placement location, and the residual conditions at the end of life, all interact with the perturbing forces to influence the exact time histories of satellite motion during free drift. They all introduce spreading effects on the individual satellites. While these factors do not produce equal spacing effects, their overall influences are dispersive in nature. Thus, the average volume per satellite is felt to be an adequate measure of the collision hazard.

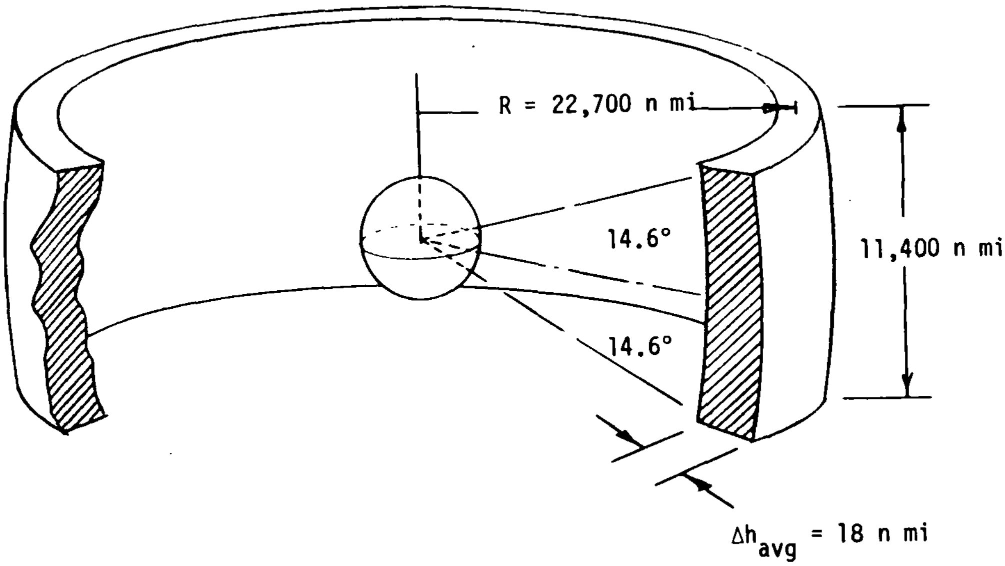


Figure 5-5. Total "Swept" Volume of Space Occupied by Free Drifting Geosynchronous Satellites

CONCLUSIONS

The following principal conclusions and key study findings were derived from the orbit saturation analysis and its related traffic definitions.

- The baseline traffic model appears conservative, particularly during the 1985-1990 time period, and does not pose serious physical or EMI contention problems within the geosynchronous satellites defined.
- The new traffic model represents the full potential for geosynchronous operations. It is based on global demands and provides increased utilitarian benefits to mankind. Satellite physical spacing was found to be acceptable within the new traffic model, but severe EMI interference was identified.
- Overall, satellite physical contention is not likely to be a critical problem through the 1990 time period, even without retrieval.
- Geosynchronous EMI contention is likely to occur before 1990 if wider spectrum usage to reduce the number of satellites operating at the same frequency is not employed by communications relay satellites.
- S-band EMI problems currently exist among users in all orbits and will be compounded by increased space traffic.
- Cooperation and planning will be required on both national and international levels to preclude physical and EMI contention.

6.0 PLATFORM REQUIREMENTS AND CONCEPT SYNTHESIS

The operational, functional, and performance characteristics of the satellites that composed the traffic models were defined to establish a data base for the derivation of two types of platforms: (1) multifunction and (2) single function or utility. The multifunction concept consisted of grouping nonrelated mission equipment into one orbital element. The utility concept was derived from a common support module that could be used by the discrete payloads of the mission models for all support function (e.g., power, stability, data management, etc.).

On-orbit servicing was a primary consideration in establishing the platform and modular packaging concepts. Servicing of up to three platforms in a region by one shuttle-tug mission was considered to be practical.

Three servicing modes (auto/remote, pressure suited, and shirtsleeve) were evaluated. Platforms tailored for each servicing mode were considered, but this approach appeared impractical. If within the span of ten years, the platforms were replaced twice because of a change in the servicing mode, the total number of platforms would approximate the satellites in the traffic model. Also programmatic flexibility to vary the servicing mode would be quite limited. In the preferred approach and configuration that was developed, the initial platform structure placed on-orbit can be serviced by all three modes. The only on-orbit modification required is to install a docking adapter to reduce a 7-foot-diameter opening, which is required for auto/remote servicing, to a standard tug-shuttle docking port for manned access.

Shirtsleeve servicing offers the greatest flexibility and capability to cope with maintenance, repair, and refurbishment activities, both planned and unplanned. Projected pressure suit technology indicates that a man in an EVA servicing mode can accomplish almost all of the activities that can be performed in a shirtsleeve mode. Articulation device development, such as that associated with the space shuttle manipulator, indicates that auto/remote servicing operations during the 1980's could approach the proficiency of manned attendance for preplanned activities. However, it is highly probable that servicing operations will become progressively more complex and less subject to planning during the mission life of platforms. Therefore, an evolutionary on-orbit servicing approach appears to be highly desirable, and perhaps even a necessity.

Subsystem trades were conducted to define an approach that would accommodate the entire range of required support. In some cases an incremental design approach was defined which would permit addition/substitution of assemblies as a function of the level of support required (e.g., solar arrays, batteries,

propellant, etc.). It was determined that the support system concepts were equally applicable to the multifunction platform approach and the discrete payload approach.

The derived platform configurations all utilized a series of toroids as the basic structure. Inside changeout of replaceable modules was required to facilitate shirtsleeve servicing operations.

Three classes of multifunction platforms were developed: (1) data relay, (2) earth observation, and (3) astro-physics. One toroid ring on each of the platforms was a common support module. Additional toroid rings were added to house the mission equipment of the three types of platforms.

The mission equipment for each of the data relay platforms could be accommodated within one toroid ring. The only significant difference between data relay platforms was the complement of antennas and RF electronic equipment.

The distinguishing characteristic of the earth observation platform was a 1.5-meter telescope, which was required to achieve adequate resolution of ground targets from geosynchronous orbit. Three toroid rings were required to house the mission equipment associated with earth-observation activities.

Incompatibilities in mission equipment and/or orientation resulted in the definition of four separate platforms for the astro-physics disciplines. They are stellar astronomy, solar astronomy, plasma physics, and high-energy physics. Both astronomy platforms included telescopes, a complete toroid ring for mission equipment support functions, and a partial ring to house the equipment that is directly associated with viewing through the telescopes. The plasma physics platform required only one toroid ring for its mission equipment. Some of the mission equipment associated with the high-energy physics platform (total absorption counter, Cerenkov counter, and magnetic spectrometer) require unique installations. The length of the required mission equipment structure is about 15 feet, but only one toroid ring can be used to house mission equipment. A separate design is required for the remainder of the 15-foot structure.

FUNCTIONAL GROUPING

The analysis of the satellite inventories of the traffic models revealed some fundamental operational requirements that any equivalent platform concept would have to meet. These requirements were:

1. Observation of weather sources
2. Global data relay capability
3. Multi-path international data relay
4. Transoceanic data relay
5. International data relay via a single platform

6. Maximum coverage of low earth orbiting satellites to a single ground station

7. Fixed local vertical, scanning local vertical, or inertially pointing orientations

The approach taken in the platform synthesis procedure was to assume that only a single platform or space element was required. Additional elements were identified only if the operational requirements so dictated.

Global Coverage

The first five operational requirements all relate to global coverage from geosynchronous orbit. If a 5-degree mask or elevation angle is assumed, then ground intercept contours for platforms located at 68° and 172°E and 6° and 110°W longitude are as in Figure 6-1. All weather sources are covered; and the national, international, and transoceanic data relay requirements are accommodated with this four-platform concept.

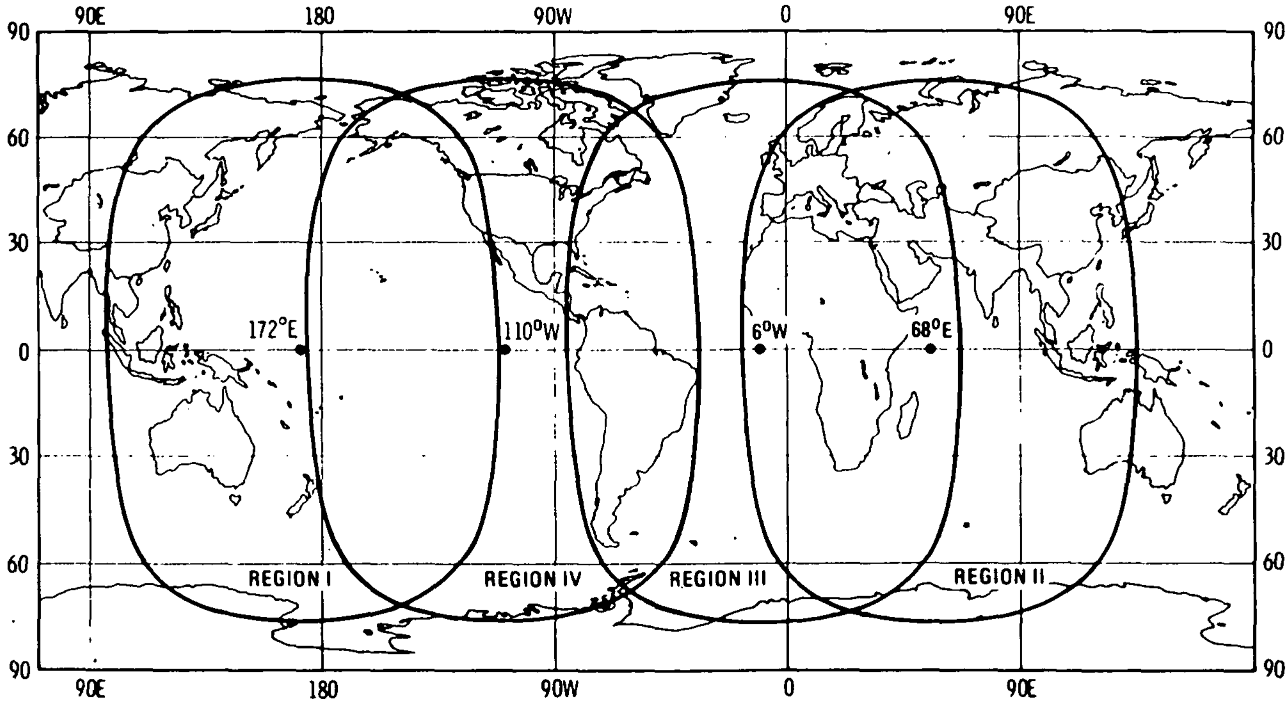


Figure 6-1. Global Coverage Regions

Solar Noise Outage

During the vernal and autumnal equinox periods, a juxtaposition of the sun, platform, and a ground station will occur for several minutes a day over an approximate two-week interval. The noise density at the ground antenna increases by approximately 85 dB during the juxtaposition period. This precludes communications from the platform.

Admittedly, the duration of noise outage is only of the order of six minutes (precise duration is dependent on orbit inclination and ground station latitude), but it is still considered intolerable. In the 1980 time frame, it is predicted that a major portion of all communications will have become dependent upon geosynchronous orbit relay. A single platform per global region would result in, for example, a main communications artery to/from Washington D.C. being disabled for about six minutes a day for four weeks a year. Clearly, this situation would be unacceptable.

Inclusion of two data relay platforms in each global region spaced at least 10 degrees apart in longitude can circumvent the solar noise outage problem. Figure 6-2 illustrates the relative positions of the sun, platforms, and ground station. Note that only a discrete section of a global region is affected by the juxtaposition at any one time. The sun included angle is only about 0.5 degree; the included angle from geosynchronous orbit to a 5-degree mask angle is 17.33 degrees.

Reallocation of real-time data relay channels will permit the division of channel capacity between the two platforms in each region rather than duplication of the total regional requirements on each platform. When service to a particular ground station is interrupted by solar noise, the channels affected can be reassigned to other links. The channels servicing the other links from the second platform can, in turn, be assigned to the affected ground station for the duration of the outage period.

Unique Placement

Operational requirement Number 6 imposes unique platform placement requirements. The Tracking and Data Relay Satellite (TDRS) system is designed to provide maximum coverage of low earth orbiting satellites via geosynchronous orbit to a single ground station. Figure 6-3 illustrates parametrically the geosynchronous element spacing and inclination as a function of the altitude of the low-orbiting element. To allow for north-south drift of the TDRS elements, a spacing of 130° in longitude is recommended. Thus, all space elements above an altitude of 700 nautical miles are capable of continuous communications via TDRS to a ground terminal.

A candidate TDRS concept locates the TDRS elements at 11°W and 141°W longitude. The single ground contact is at Rosman, North Carolina. The cones of exclusion at low altitudes with this TDRS configuration are illustrated in Figure 6-4. Satellites within the region extending from about the middle of India to the middle of Australia at altitudes of 100 nautical miles or less would not be within the line of sight of a TDRS element.

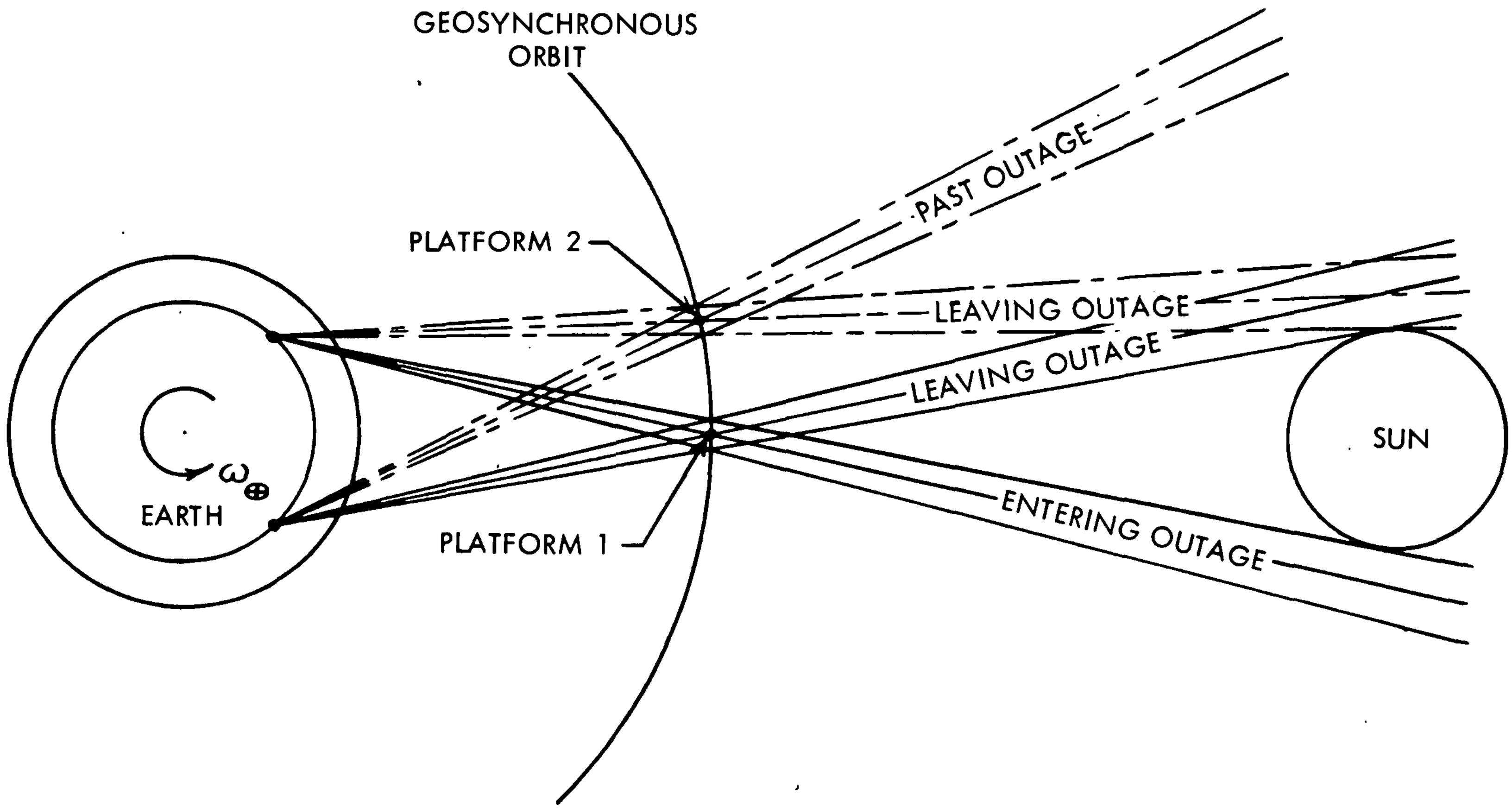


Figure 6-2. Solar Outage Geometry

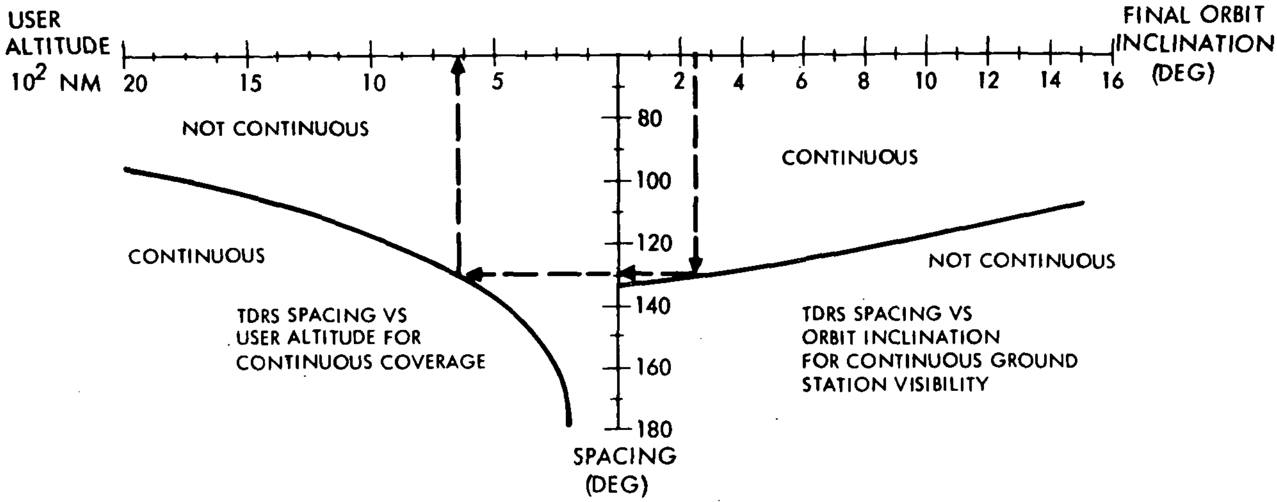


Figure 6-3. Optimized TDRS Spacing

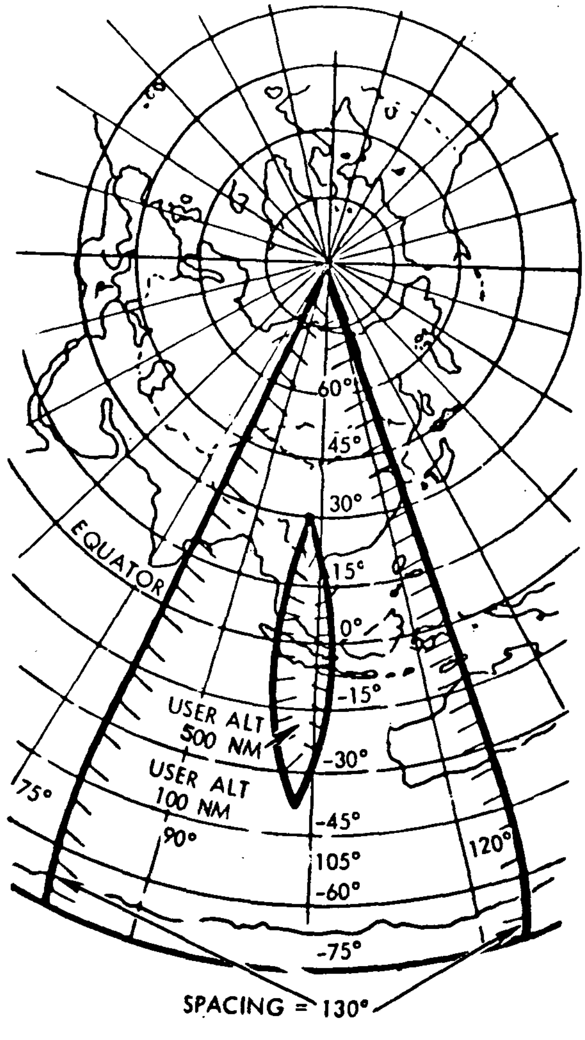


Figure 6-4. Cones of Exclusion

Reduction of the longitudinal spacing of TDRS elements to conform to the approximate 90-degree spacing of the data relay would result in an unacceptably large cone of exclusion of low-orbiting satellites. Therefore, TDRS platforms can not be grouped with data relay platforms because of their unique placement requirements.

Orientation Considerations

Observation of weather sources is only one role of the earth-observation class of geosynchronous spacecraft. Earth resources survey, hydrology, meteorology, etc., are also integral parts of this class. In order to obtain adequate resolution from a geosynchronous altitude, a telescope of the order of 1.5 meters is required. This, in turn, requires a local vertical scan through the 17-degree included angle from geosynchronous orbit. Global coverage requires a minimum of four platforms, but operationally they are not compatible with data relay platforms. The data relay links require fixed local vertical pointing to within 0.2 degree. The earth observation platform must scan through a 17-degree angle.

Astronomy-space physics operations require the capability for 4π steradian pointing. Inertial hold for long durations (days) is mandatory. This class of space elements is incompatible with both the data-relay and the earth-observation functions. The relative size of the vehicles that house the various functions precludes any reasonable design that would accommodate dual orientations to the required accuracies (arc second/second stability for earth observations and astro-physics payloads).

Developmental Payloads

Several of the payloads identified in the mission models for the 1980's consisted of sensor/system concept evaluations. At this point in time, it is unrealistic to attempt to define these payloads to a level that might permit integration into a multifunction platform. In addition, grouping experimental equipment with operational equipment that the world population has become dependent upon is highly questionable because of the potential risk factors. A more realistic approach is to design a developmental orbital facility which would provide flexibility in both the mission equipment complement and operational capability. It may be feasible that the basic structure and support systems of the operational platforms could be used in the developmental facility for as yet undefined developmental payloads. This is the approach taken in this study.

Navigational and Traffic Control

The new traffic model identified navigation aids to aircraft and ships, as well as traffic monitoring/communications functions. Also, coverage of the polar routes was required. Therefore, a platform for each global region is inadequate to fulfill these requirements. One proposed concept is illustrated in Figure 6-5. A constellation of five satellites, one at geostationary and four in inclined geosynchronous orbits, is required in each global region. Obviously the elements in the inclined orbits cannot be grouped. The element at geostationary could be combined with a data relay

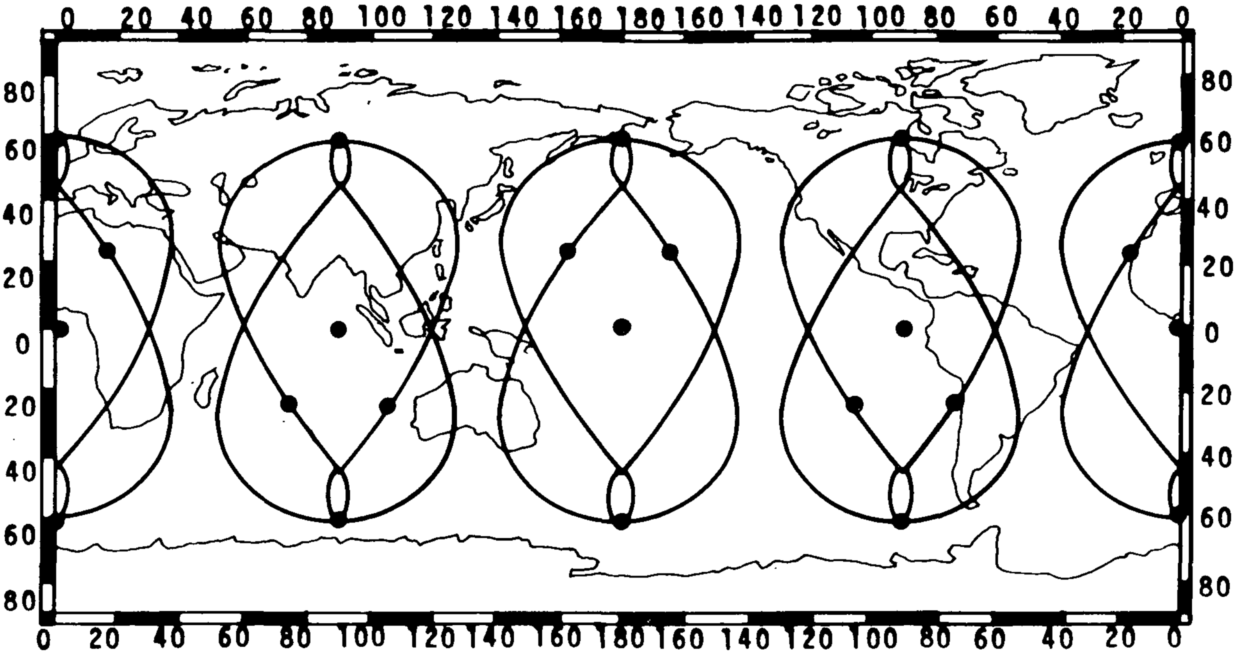


Figure 6-5. Nacsat Platform Orbital Tracks

platform. However, because this element is essentially the same as those in inclined orbits, it was decided that there were fewer advantages to grouping the geostationary functions. The primary comprison was:

> 20 almost identical navigation and control platforms and the data relay platforms

and

> 16 identical navigation and control platforms,
> 4 combined navigation-traffic control/data relay platforms, and the remainder of the data relay platforms

Although the latter concept requires four fewer elements, it would require three development programs instead of the two required by the first alternative. It is believed that the first approach would be more cost effective.

Summary

The functional grouping analysis indicated that six types of platforms are required. The specific number of each type platform is dependent upon the traffic model. Table 6-1 lists the types and minimum number required.

Table 6-1. Multifunctional Platform Grouping

Platform Type	Functions Combined	Limiting Factor	Minimum Requirements
Data relay	Comsat, Domsat, Intelsat, traffic monitor[1]	Global coverage, solar noise outage	8
TDRS	---	Unique placement	3[2,3]
Earth observations	Meteorology, hydrology, earth resources	Global coverage, orientation requirement	4
Astro-physics	---	Orientation	4[3]
Developmental	Intermediate	Undefined sensors/ concepts; risk factor	?
Navigation and traffic control[4]	---	Navigation aid; polar route coverage	20

1. Traffic monitor function included for baseline mission model only
2. On-orbit spare included
3. Reflects baseline traffic model only
4. Applicable to new traffic model only

SERVICING CONSIDERATIONS

In order to evaluate the potential impact on platform design and programmatics, ancillary servicing equipment was synthesized. One concept accommodated auto/remote servicing; the other concept accommodated both pressure-suited and shirtsleeve servicing operations. Weights and volumes were estimated for the ancillary equipment in order to establish the available payload weight for platform module replacement. Manned servicing required a tandem tug concept because the crew module alone exceeded the roundtrip capability of a single stage tug.

Gross timelines for servicing operations in all three modes were developed. The constraint on the operation was the seven-day mission duration limit of the space shuttle model used in this study.

An evaluation of the feasibility of multi-platform visits on a single mission was conducted on the basis of mean weights of replaceable modules and a mean number of modules per platform. Within the limits of the model used, it was determined that a 25-percent replacement of the modules of three platforms could be accomplished on a single mission. The first constraint reached in the auto/remote servicing mode was weight. Ample mission time was available for the required module replacement operations. In the model used, it was assumed that two 8-hour shifts by ground controllers would be employed. If need be, a third shift could be implemented. Conversely, for the manned servicing modes, time was the first constraint reached; weight was not as significant. Only a single crew (two or three men) was hypothesized for on-orbit servicing. The dual tug configuration for manned attendance results in a major increase in allowable payload weight.

Ancillary Equipment

The baseline concept for interchange of platform modules in the auto/remote servicing mode consisted of a toroid ring(s) and a manipulator assembly. A second manipulator with a TV camera is also included. The concept is illustrated in Figure 6-6. Weight estimates of both one and two-tier concepts are listed in Table 6-2.

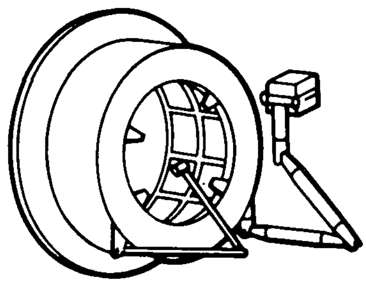


Figure 6-6. Auto/Remote Service Unit Concept

Table 6-2. Auto/Remote Servicing Unit Weight Summary

Assembly	1 tier (lb)	2 tier (lb)
Docking mechanism	100	100
Manipulators and TV arm	400	450
Structure	400	800
Adapter	100	150
Unit subsystems (TV electronics, TPS, docking aids)	150	150
TOTAL	1150	1650

The baseline tug is an unmanned element. In this study the provisions for crew and module replacements were integrated into a single concept. The concept is illustrated in Figure 6-7. The weight summary is presented in Table 6-3.

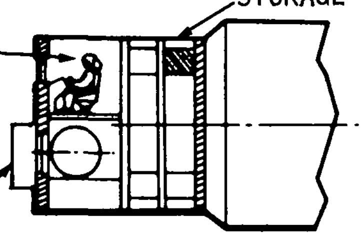


Figure 6-7. Manned Servicing Unit Concept

Table 6-3. Manned Servicing Unit Weight Summary

Assembly	1 tier (lb)	2 tier (lb)	3 tier (lb)
Docking mechanism	100	100	100
Primary structure	800	900	1000
Secondary structure	1450	1750	2050
Subsystems	3000	3000	3000
Adapter	250	300	350
TOTAL	5600	6050	6500

The concept is applicable for both pressure-suited and shirtsleeve servicing operations. An airlock was not included. Depressurization of the crew compartment would be required for pressure-suited operations.

Payload Capabilities

The payload capability of the tug, based upon two-tier servicing system concepts, is indicated in Figure 6-8. The solid lines indicate the total tug payload capability; the dashed lines indicate the available repair/replacement/refurbishment weight after the servicing equipment is extracted from the total.

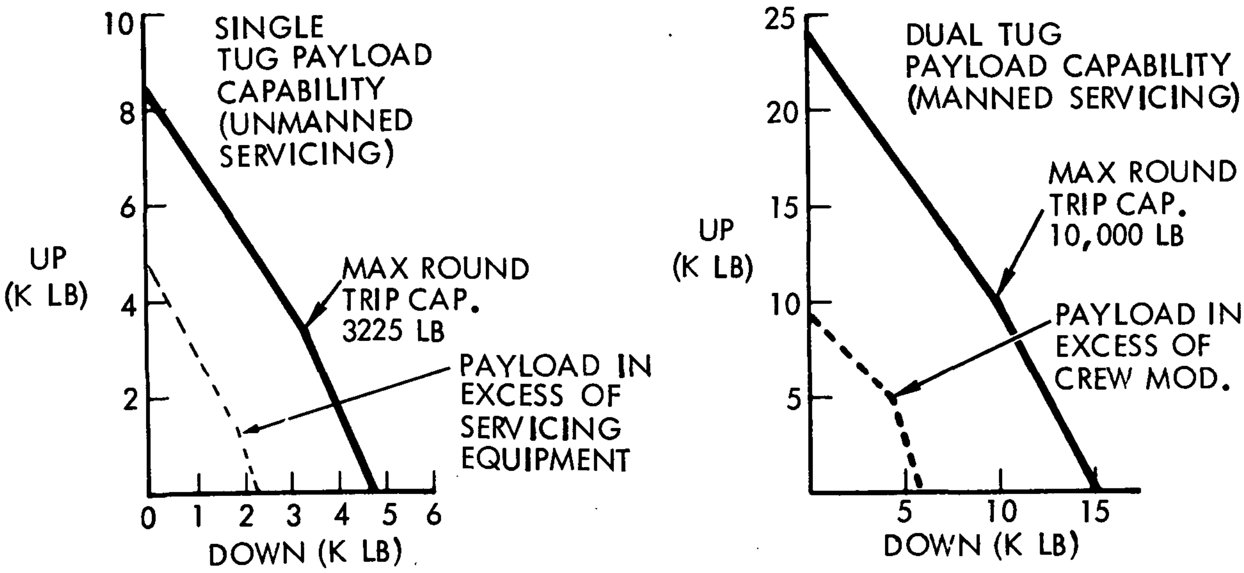


Figure 6-8. Servicing Mission Payload Characteristics

Servicing of more than one platform on a single mission further reduces the roundtrip payload capability of the tug. Table 6-4 indicates the payload capability for the one, two, or three platform servicing missions. The payloads reflect a 5-degree longitudinal separation between platforms and a 24-hour phasing maneuver for transfer between platforms.

Table 6-4. Payload Capabilities for Multi-Platform Servicing Missions

Servicing Mode	Platforms Serviced	Total Roundtrip Payload Weight (lb)
Unmanned (single tug)	1	3,225
	2	3,085
	3	2,925
Manned (dual tug)	1	10,000
	2	9,850
	3	9,700

Servicing Mission Timeline

The time required to service platforms is equally as important as the payload limitations. The baseline space shuttle used in this study was sized for a seven-day mission. Nominal timelines for the entire servicing mission were developed to establish any potential constraints. Twenty-four hours were allocated for the initial and final phases of the mission (liftoff to tug-platform dock and tug-platform separation to touchdown, respectively). Also, 24 hours were allocated for the 5-degree orbit transfer between platforms. Thus, the total times available for servicing platforms based upon a seven-day mission are:

One platform	120 hours
Two platforms	96 hours
Three platforms	72 hours

A step-by-step operational sequence for platform module interchange was developed for each of the three servicing modes. Table 6-5 summarizes the activity time for each mode.

Table 6-5. Time Durations of Servicing Activities

Servicing Mode	Fixed Time (hours)		Module Interchange (minutes)
	Per Platform	Per Day	
Auto/remote	3.5	-	15
Pressure suited	2.5	6	30
Shirtsleeve	7.5	-	15

The fixed time "per platform" includes deactivation and inspection, as well as reactivation and verification, of the platform. The "per-day" requirement for pressure-suit operation includes the donning and doffing operations associated with pressure suits.

Servicing Capabilities

On the basis of the guidelines previously defined, single mission servicing capabilities were evaluated for all three modes. Mean weights and numbers of replaceable modules for the platforms were used. Figure 6-9 illustrates the capabilities. All three modes can accommodate a three-platform, 25-percent module interchange mission. A 50-percent interchange can be effected on a dual- or two-platform servicing mission. All three modes can accommodate a 100 percent changeout of a single platform.

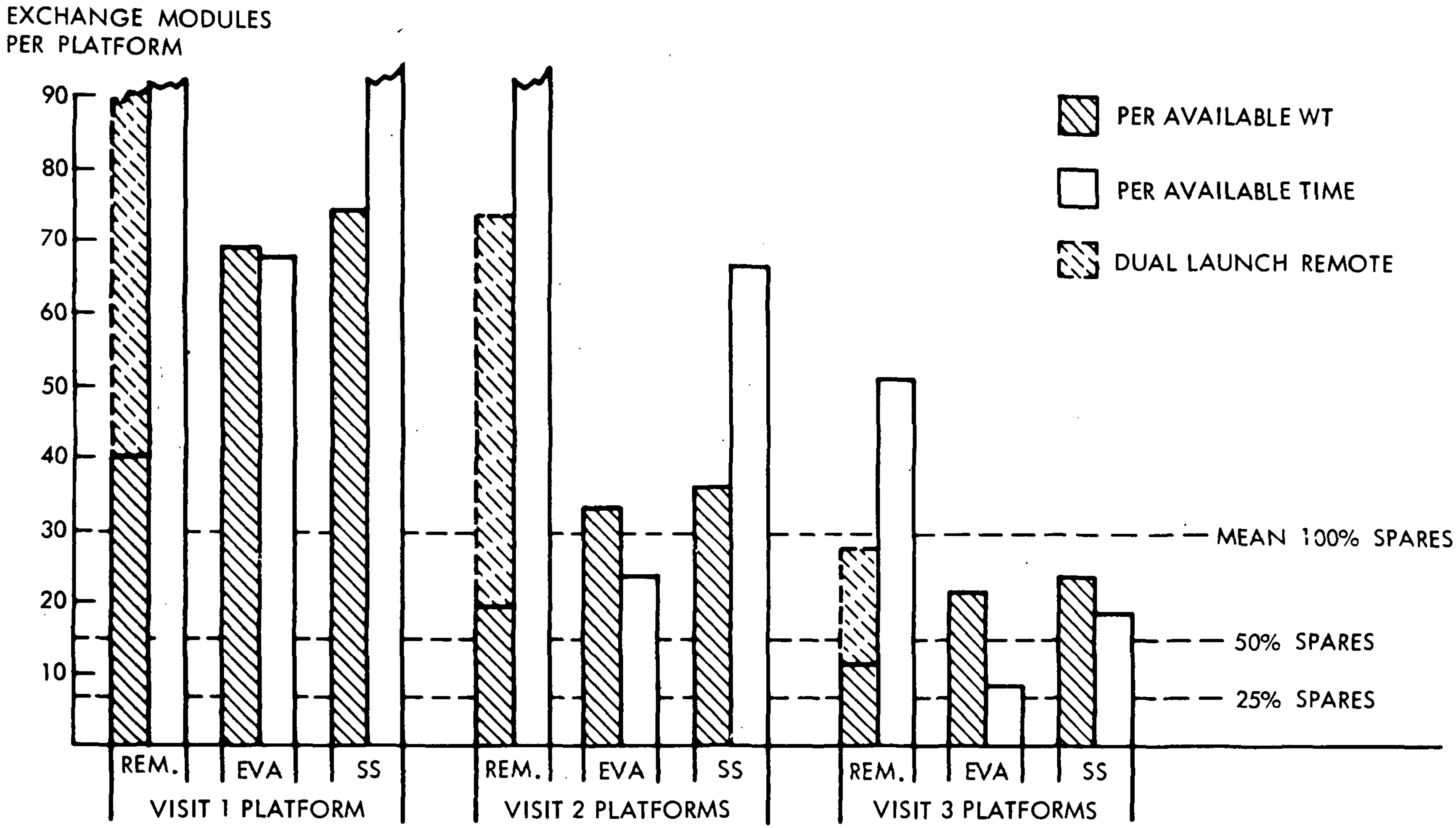


Figure 6-9. Servicing Capabilities

The primary constraint in this model is the servicing time available, especially in the pressure-suited mode. Auto/remote servicing time was based on two 8-hour shifts for ground controllers. If in practice the time limit should present a problem, it could be resolved (with some shuttle payload penalties) by extending the on-orbit stay time of the shuttle.

The apparent weight constraint associated with the auto/remote servicing mode is indicative of the single tug logistics concept. The weight capability for tandem tug-dual shuttle launch operations comparable to the manned servicing mode is also indicated on Figure 6-9. Only a three-platform servicing mission would be efficient for a dual tug-auto/remote configuration.

Servicing Mode Limitations

Although a platform could be optimally designed for each servicing mode, all three modes have inherent practical limitations. Shirtsleeve servicing provides the greatest flexibility in operations. Unanticipated problems can be more readily resolved; repairs to a much lower level of assembly can be accomplished; and hardware, including the wire harness, can be refurbished. The limitation to shirtsleeve servicing is that it cannot accommodate the replacement/repair of platform appendages that cannot be enclosed in a pressurizable environment. The EVA servicing mode alleviates the problem of platform appendage servicing, but the lack of dexterity and restriction of movement in a pressure suit preclude some operations that man can accomplish in a shirtsleeve mode. The principal advantage of the auto/remote concept is the removal of man from a hazardous environment. Also, only a single shuttle/tug flight is required for the servicing mission. However, the major disadvantage to auto/remote servicing is the relative inflexibility for contingencies and unexpected problems.

The projected technology associated with pressure suits indicates that during the 1980's, a pressure-suited man will be able to accomplish from 90 to 95 percent of the activities that a man can perform in a shirtsleeve environment. The small delta could be the difference between on-orbit refurbishment of a platform instead of replacement of the space element. The primary difference between platform designs for EVA and shirtsleeve modes would be a pressure shell, required for the shirtsleeve mode, which would increase the platform weight by approximately 200 pounds. The impact on the servicing system would be the delta equipment for storage and control of the atmosphere for making the platform habitable, the servicing system weight increasing by about 50 pounds. Storage volume requirements increase less than one cubic foot.

The advancing technology associated with articulation devices such as the space shuttle manipulator indicate that it would be feasible to accomplish modular assembly replacement by remote control. More complex operations could also be accomplished if adequately defined and an appropriate manipulator end effector and force feedback control system were developed. However, the problem is to identify such operations as platform repair and/or refurbishment in time to permit the necessary development. It should be noted that the more complex the auto/remote operation, the more significant is the 0.1-second communication time delay between geosynchronous orbit and a ground control

station. The principal advantage associated with the auto/remote concept is the simplification of the logistics system, since only a single tug/shuttle is required. Both man-attendance modes require dual tug/dual shuttle operations.

It appears that an evolutionary servicing concept is appropriate for a platform program. Initial module replacement can be achieved by the auto/remote concept. As the platform program progresses, repairs and refurbishment will probably be required and more complex and intricate operations will be necessary. This type of activity is more amenable to man attendance. Further, the projected development of the tug supports the evolutionary concept. Initial IOC of the shuttle and unmanned tug supports the early phase of on-orbit servicing of platforms at the modular interchange level. Approximately five years after initiation of platform operations, a man-rated tug is planned. This timing would support potential refurbishment of platforms utilizing the shirtsleeve mode.

SUBSYSTEMS AND PACKAGING

One of the prime drivers in the selection and synthesis of subsystems and packaging concepts was the desire for maximum commonality across all platforms. It is believed that one of the keys to a cost-effective space program is a reduction in customized design approaches for each space element and repair/resupply/refurbishment/reuse of space elements. The approach taken in this study was to select the design concept that satisfied the most stringent performance requirements and facilitated both auto/remote and man attendance on-orbit servicing.

Support Requirements

The performance requirements of the individual satellites of the traffic models and gross platform concepts were analyzed to establish the operating ranges that a common support module would be required to accommodate. In selected cases, performance plateaus were also defined. Although the main emphasis was to establish a singular concept for each support function, the quantity of a particular type platform requiring a less stringent capability (and thus less costly equipment) may justify a separate development. Table 6-6 summarizes the performance ranges.

The performance plateaus that were specified for concept development were as follows:

Electrical power system	500; 1000; 1500; 2000 watts
Attitude stabilization and control	
Pointing	0.1 degree; 0.1 arc second
Stability	0.1 degree/sec; 0.1 arc second/second
Propulsion	12,000 lb-sec; 19,000 lb-sec
Orientation	Fixed local vertical; inertial

Table 6-6. Subsystem Performance Requirements

Function	Performance Requirement Range
Electrical power	200 watts to 2K watts average
Power dissipation	200 watts to 2K watts average
Turn down ratio	20:1
Temperature limits	40° to 70°F
Average assembly dissipation	10 to 500 watts
Orientation	Fixed local vertical; scanning local vertical; variable inertial
Pointing	0.1 degree to 0.1 arc second
Stability	0.1 degree/sec to 0.1 arc second/second
Slew rate	0.5 min/sec to 0.1 degree/second
Data rate	10 Kbps to 50 Mbps
Command rate	1 Kbps to 10 Kbps
Propulsion	12,000 lb-sec to 19,000 lb-sec impulse

The various power levels can be readily accommodated within the preferred concept, solar array-batteries. Both the solar arrays and the battery pack are replaceable modules, and various power capacity designs could be structurally interchangeable. The preferred attitude stabilization and control concept varies significantly between performance levels. The less stringent requirements are associated with data relay platforms, which require a fixed local vertical orientation. On the basis of current technology-developed hardware, a two-reaction, wheel-momentum, bias-horizon scanner is preferred. The more stringent requirements, coupled with inertial orientation, dictates a 3-reaction wheel system and star trackers. The two concepts/assemblies are not readily interchanged.

Electrical Power Subsystem (EPS)

Design concepts for the three major functions of the EPS were evaluated. A synopsis of the alternates is shown in Figure 6-10.

The preferred power generation concept was solar arrays. The selection was based upon relative cost, weight, and availability of hardware. For example, an advanced solar array will yield more than four times as much wattage per pound than either the radioisotope or nuclear concepts.

Consideration of the servicing modes also favored the solar array concept. Because manned servicing is included, significant increases in shield weight and safety features are required with either the nuclear or radioisotope concept.

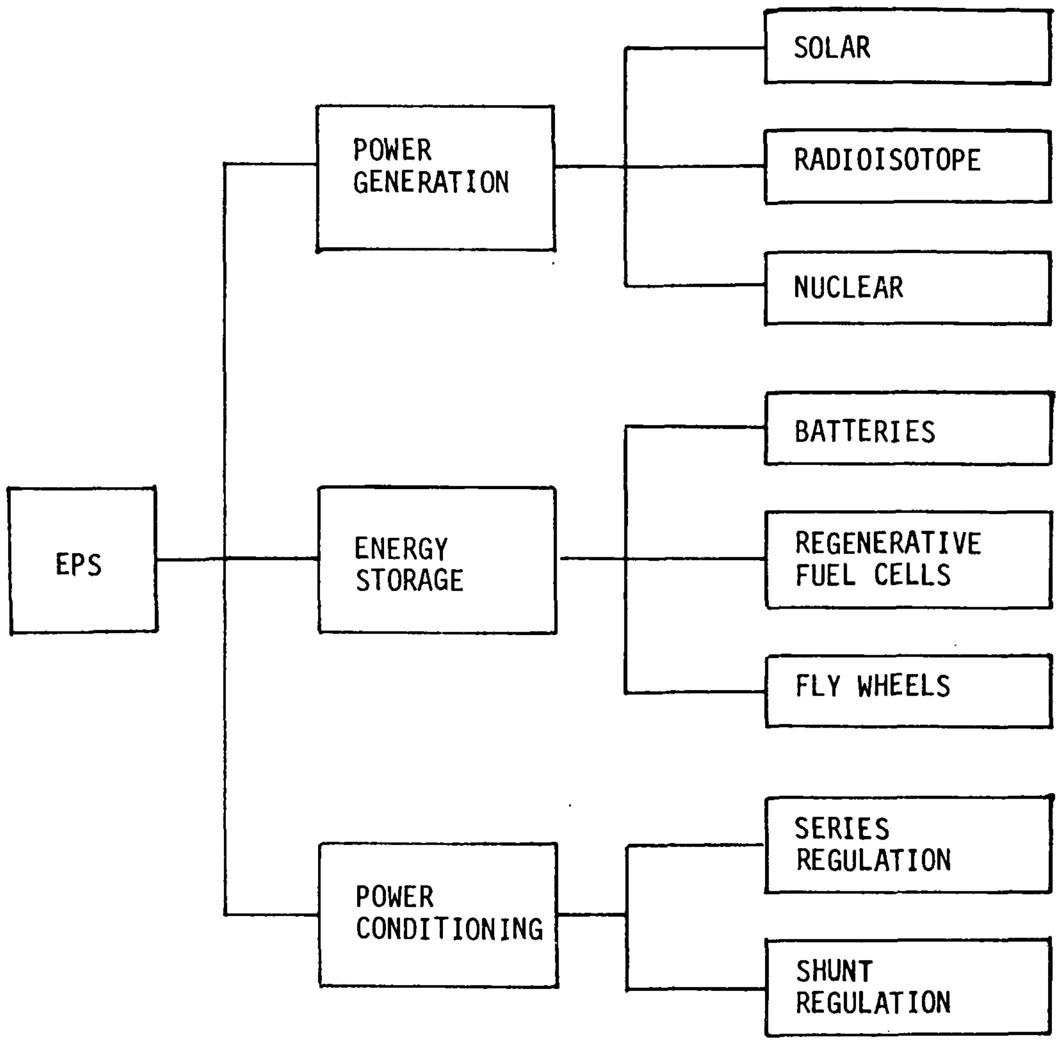


Figure 6-10. EPS Concept Trades

The selected energy storage concept was NiCd batteries. Because of the nature (duration and frequency) of the eclipse periods of a geosynchronous platform, it is believed that batteries can be effectively used for long mission durations. The depth of discharge and discharge cycles at geosynchronous orbit are significantly less than at low earth orbit.

The other two candidate concepts, regenerative fuel cells and fly wheels, are classed as emerging technologies. The fly wheel concept consists of an integrated power and attitude control system (IPACS). During the sunlight portion of the orbit, solar array power is used by an electric motor to increase the speed of a fly wheel that is part of a control moment gyro assembly. During eclipse periods, energy is taken from the wheel to operate a generator to supply power to the loads. Depending upon the rate of development, either one of these alternates could be preferred by the 1980's. Both concepts have higher watt-hour/pound ratings than batteries. However, the uncertainty in component

development for these two concepts for long-duration missions and the potentially higher costs precluded their selection.

The series regulation concept has been and is being used on many space elements. Its primary disadvantage is the 10 to 15 percent power losses incurred by channeling all of the load power through the regulator. A shunt regulator approach, the direct energy transfer concept, is currently being considered for advanced communication satellites. It includes a central control that modulates the operation of a shunt regulator, battery charge regulators, and a battery discharge regulator. Continuously regulated power is provided without an in-line conditioning element. Bus voltage regulation of $\pm$ 1.0 percent (28 volts bus) is readily obtainable. The reduced weight and higher efficiency of the direct energy transfer concept are the primary reasons for its selection as the preferred approach.

Telemetry, Tracking, and Command Subsystem (TT&C)

The most significant trade study conducted for TT&C functions was that associated with the carrier frequency used for data transfer between ground stations and platforms. Use of S-band (2.1 to 2.3 GHz) for this function has seen the approach in the vast majority of the space programs for a decade. Worldwide S-band ground terminals have been established for low-orbit satellite programs. These same stations could be used for geosynchronous platforms also. However, just the predicted increase in low-orbit satellite traffic will severely tax the capacity of the S-band system. Only a single ground terminal is required for data transfer to/from geosynchronous platforms; it is not mandatory that the link be compatible with the current worldwide S-band system.

The majority of the geosynchronous platforms are data relay types. Because of mission equipment bandwidth requirements, C- and K-band frequencies are used. It is anticipated that the user ground station would perform the status-monitoring as well as the payload-utilization function. In order to maximize the commonality of both platform and ground station equipment, either a C- or K-band TT&C carrier frequency is preferred. The increasing demand for channels and thus bandwidth will probably result in K-band mission equipment on all data relay platforms. Since the beamwidth at K-band is smaller than the beamwidth at C-band for the same antenna size, K-band is preferred. The narrower beam will reduce potential interference with other ground stations.

Up-command communication link calculations were made for both S-band and K-band TT&C systems. Although the K-band system requires 14.5 times the power of the S-band system for the same performance margin, the level is only about 500 milliwatts. Thus the K-band system was selected for TT&C purposes to maximize commonality of equipment and minimize RF interference problems.

Attitude Stabilization and Control Subsystem (ASCS)

The key elements of an ASCS are the torque-source and attitude-reference assemblies. The low-disturbance torques encountered at geosynchronous orbit suggest momentum storage/transfer system (MSTS) concepts as a prime candidate for cyclical torques. Slew rates for the platforms are relatively low

(0.1 degree/second), so that reaction wheels are applicable. Secular torques plus stationkeeping requirements establish the necessity also for an auxiliary propulsion system.

For attitude determination, sun, stellar, horizon, and inertial sensing instruments are available. However, platform control necessitates a moderate bandpass requirement, and many of the potential combinations of sensors and torques require an inertial reference system (gyros) also. Depending upon the control accuracies required, integrated ASCS concepts are available that preclude a separate attitude reference assembly.

Three types of platforms that have distinct ASCS requirements were evaluated: (1) data relay, (2) earth observation, and (3) astro-physics. The data-relay platform had the least stringent requirements, and thus the simplest system was selected as the preferred concept. It consists of a "T" momentum bias configuration in which an earth horizon sensor is scanned by the momentum bias wheel. The earth-observation platform is subjected to the most severe disturbance torque environment and has the most stringent cyclic maneuver requirements. However, its near local vertical orientation also permits the use of a momentum bias concept, a two-degree-of-freedom gimbaled reaction wheel. Performance accuracies require a star tracker system for attitude determination. The variable inertial orientations associated with astro-physics platforms result in the requirement for a conventional triad momentum wheel configuration for the MSTS. A star tracker concept is also required for this type of platform to achieve the required pointing accuracies.

A comparison of the ASCS concepts for the three types of platforms is presented in Table 6-7. Although the concept for the astro-physics platform would be rated lowest in all categories, it is the only one of the three that is applicable to all three platforms.

The difference between the astro-physics and earth observation platform ASCS concepts can be attributed to the additional reaction wheel required for the former platform. The relatively low cost of the data relay ASCS concept reflects the off-the-shelf availability of horizon scanners and the integral packaging of the momentum wheels and the scanner. This could be misleading for two reasons: (1) complexity of installation in a platform, and (2) in-process development of change-coupled device (CCD) star trackers.

Inclusion of a horizon scanner in a standardized platform concept presents some unique problems. All the sensors (antennas) associated with data relay platforms are earth pointing. The associated electronics hardware should be located as close as practical to the antennas to reduce line losses. Thus a support function (ASCS) would be intermingled with mission equipment in order to also achieve earth viewing. The ASCS could not be located in a common support module unless the horizon sensor was extended on a boom beyond the moldline of the platform.

Table 6-7. ASCS Concept Comparisons

Mission	System	Weight (∿lb)	Average Power (∿watts)	Peak Power (∿watts)	Estimated Relative Cost (%)
Data relay	"T" momentum bias & wheel-scanned horizon sensing	66	45	236	43.7
Earth observation*	Two-degree-of-freedom gimbaled momentum wheel & strapdown star sensors	105	62	296	96.5
Astro-physics**	Three orthogonal reaction wheels & strapdown star sensors	149	80	406	100.0

*System also accommodates data relay requirements
**Compatible with requirements of all missions

The CCD is essentially a solid-state digital imaging sensor. Its technology is emerging and may have applications in commercial television. Prototype hardware has been developed, and system feasibility studies have been conducted. The primary factor in the higher estimated costs for the earth observation and astro-physics ASCS concepts is the uncertainty of the operational status of the CCD concept. Current interest in the devices could accelerate their development to the point that they would be cost competitive with horizon scanners.

This concept was selected as the preferred control system approach for geosynchronous platforms on the basis of the universal applicability of the triad reaction wheel-CCD ASCS concept and the potential low-cost availability of the CCD's.

Platform impulse requirements range from 10K to 20K lb-sec. For the requirements range, a monopropellant hydrazine concept was selected over cold gas or earth storable liquid propellants on the basis of system weight, cost, existing technology, and ease in propellant handling. The maximum propellant requirement was established by the astro-physics platforms (82 pounds). Two diametrically opposite modules, with eight 1-pound-thrust engines each, could provide the necessary momentum dump, orientation, and stationkeeping maneuvers.

The structural concept for the common support module will accommodate up to four propulsion modules. The initial concept for data relay platforms did not include a requirement for north-south stationkeeping. (It has not been established that this is a firm operational requirement.) But by including the two additional propulsion modules, up to 2.5 years of north-south stationkeeping

of data relay platforms can be accomplished before propellant replenishment is required. Analyses in other non-related studies that pertained to ground station concepts indicated a strong preference for north-south stationkeeping of data relay elements. On the basis of this preference and the potential increase in reliability and mission duration, the four-propellant module approach was selected for the common support module.

Figure 6-11 illustrates the propulsion module concept. Also illustrated is a hinged engine assembly cover. Upon closing the cover, a pressure seal is established around a cutout in the basic structure. Shirtsleeve maintenance/ replacement is thus feasible from within the support module.

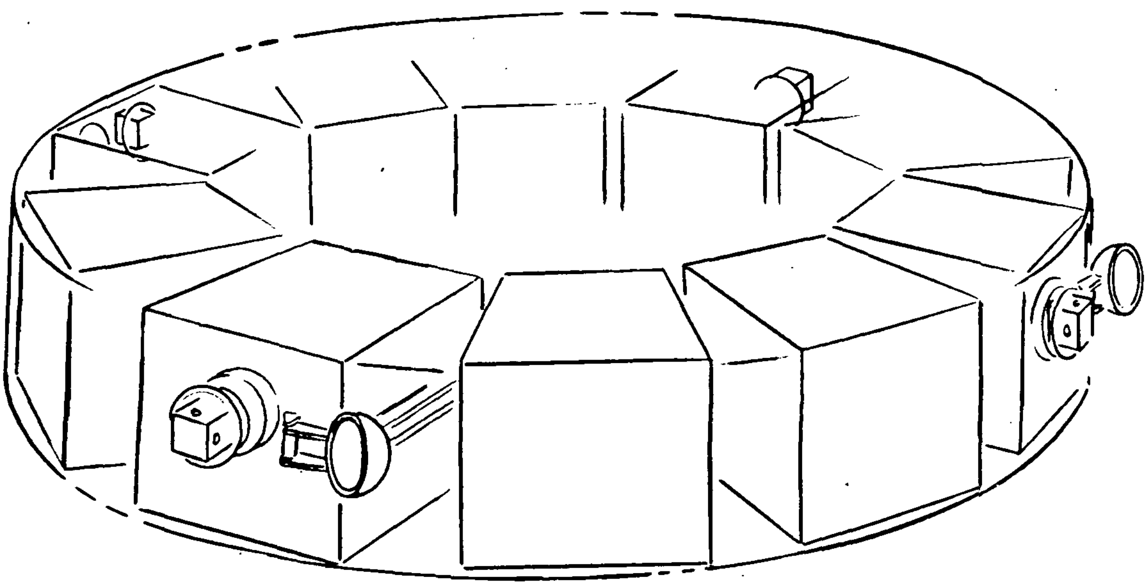


Figure 6-11. Reaction Control System Concept

Thermal Control Subsystem (TCS)

The structural configuration of geosynchronous platforms directly affects the selection of the TCS concept. Shirtsleeve maintenance requires a pressurizable structure and inside changeout of modules. Thus, a heat transport system to conduct the heat from a module to an external radiator is required. A heat pipes system was selected for two reasons: (1) it is a passive system and thus highly reliable, and (2) the design concept can readily accommodate large power (thermal) turndown ratios. Although data relay platforms will operate at full power almost continuously, both earth observation and astrophysics platforms will operate cyclically at power levels ranging from as low as 100 watts to as high as 2000 watts.

One minor problem associated with on-orbit changeout of modules is making and breaking the thermal interface between the module and the TPS coldplate. The recommended approach was to include a thermal grease packet in the coldplate interface for all modules requiring greater than 100 watts power dissipation. Upon installation of the module the packet is crushed and the thermal connection is adequately established.

A radiator area of approximately 22 square feet (in two sections) is required for the common support module and the mission equipment rings for the data relay platforms. The power dissipation requirements of the mission equipment rings for earth observation and astro-physics platform vary considerably. The largest radiator requirement was for one of the equipment rings for the earth observation platform; it required 72 square feet of radiator. The structural concept can readily accommodate two 36-square-foot panels.

Environmental Control Subsystem (ECS)

Inclusion of ECS provisions in a geosynchronous platform was evaluated. Because of the potentially long duration (years) between servicing visits and the ECS capabilities of a manned tug, it was deemed to be impractical to include ECS equipment as part of the platform.

The delta manned tug ECS requirements to facilitate shirtsleeve servicing of platforms were defined. Table 6-8 summarizes these requirements. Pressure tanks and the air supply are expressed parametrically because they both are a function of the number of platforms that will be visited on a servicing mission. In order to provide service mission flexibility without penalizing the basic tug, it was recommended that all ECS equipment (especially the pressure tanks) associated with making the platform habitable be installed in the storage compartments of the servicing unit, instead of in the basic tug ECS subsystem.

Table 6-8. Delta Manned Tug ECS Requirements

Component	Quantity	Unit Weight (lb)	Size (in.)		Power (watts)
			Length	Diameter	
Duct	1	6	84	8	
Duct coupling	1	10	9	5	
Ventilation fan	2	2	4	6	15
Fire detector	1	6	6	6	10
Platform vent valve	2	3	2	4	
Pressure tanks		1 lb/lb air			
Consumable Air		7.5 lb/100 ft^3			

Structures

Several NASA and contractor studies are evaluating various space element configurations that will facilitate on-orbit servicing. The one guideline of this study that makes the configuration definition unique is the requirement for an evolutionary concept that will progressively accommodate auto/remote, pressure-suited, and shirtsleeve servicing. The most practical configuration for shirtsleeve operations in an orbiting space element is a cylinder. The maximum diameter of the element must be compatible with the space shuttle cargo bay -- 15 feet. Interchange of modules must be accomplished from the interior in the shirtsleeve servicing mode. Auto/remote servicing could be accomplished by various articulation devices. Cartridge-type mechanisms could be used for external changeout. Manipulators similar to those of the space shuttle could be used for either inside or outside changeout. No special structural provisions other than restraints were identified for pressure-suited operations.

An evolutionary concept can be one that minimizes design changes as a program progresses; either the basic unit is updated or replaced with the updated configuration. The evolution of servicing modes was assumed to occur through the 1980's. But one of the prime drivers for on-orbit servicing is to extend the usable life of a space element up to ten years. Therefore, the approach for this study was to define a platform configuration that could be adapted on-orbit to the three servicing modes. Replacement of the basic space element was not considered to be an acceptable solution.

Since conversion from a non-pressurizable to a pressurizable volume on orbit was determined to be impractical, the preferred shape of the platform configuration was cylindrical. Also, inside changeout of modules was required. Auto/remote servicing of inside changeout modules imposed requirements for clearance and articulation of the manipulator and attached modules. An unencumbered 7-foot-diameter volume in the center was selected for the interchange operation.

Consideration of appendages (jets, hinge points, rolled-up solar arrays) and module sizes indicated that a reasonable compromise for the outside diameter of the platform structure was 12 feet. This size allowed a 1.5-foot clearance in the shuttle cargo bay and accommodated 12 radially mounted replaceable modules 24 by 20 by 24 inches. The resulting toroid configuration of the basic platform structure is illustrated in Figure 6-12.

Standardized modular packaging was selected to simplify the replacement operation. If all modules are the same size, then the servicing unit needs only one empty storage compartment at mission initiation. Customized packaging would require either two manipulators, a temporary holding fixture, or multiple empty storage compartments that would be resized for each specific mission. Also, one more opportunity for potential cost savings from commonality would be forfeited.

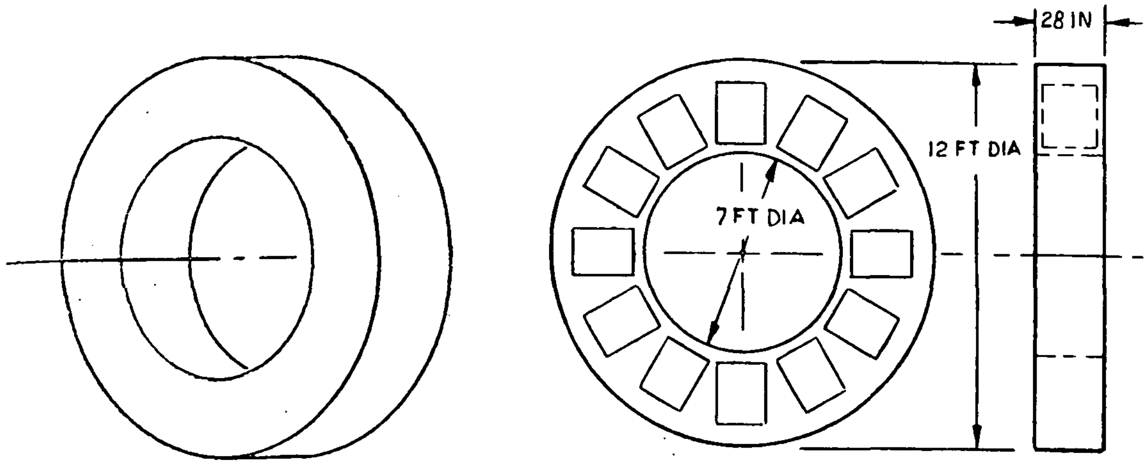


Figure 6-12. Basic Platform Structural Configuration

Replaceable Module Packaging

Conceptual design of each of the support system assemblies was performed to establish their physical characteristics. Grouping of subassemblies was based upon servicing considerations, volumetric requirements, power dissipation, and interface complexity. The resultant grouping and the rationale for it are presented in Table 6-9.

A total of 12 replaceable subsystem modules are identified. The data processing and tracking/telemetry assemblies are packaged in one module, referred to as the central processor. Included in the 12 modules are the two attitude control or propulsion modules that are in excess of the basic requirements as explained in the preceding attitude stabilization and control description.

All of the assemblies can fit in the standard 24 by 20 by 24-foot modular envelope. Two of the assemblies (propulsion and reaction wheels) utilize almost the entire volume available. All other assemblies could readily accommodate growth or redundancy provisions. The configuration of the platform support system or common support module is illustrated in Figure 6-13. Weight and power characteristics are presented in Table 6-10.

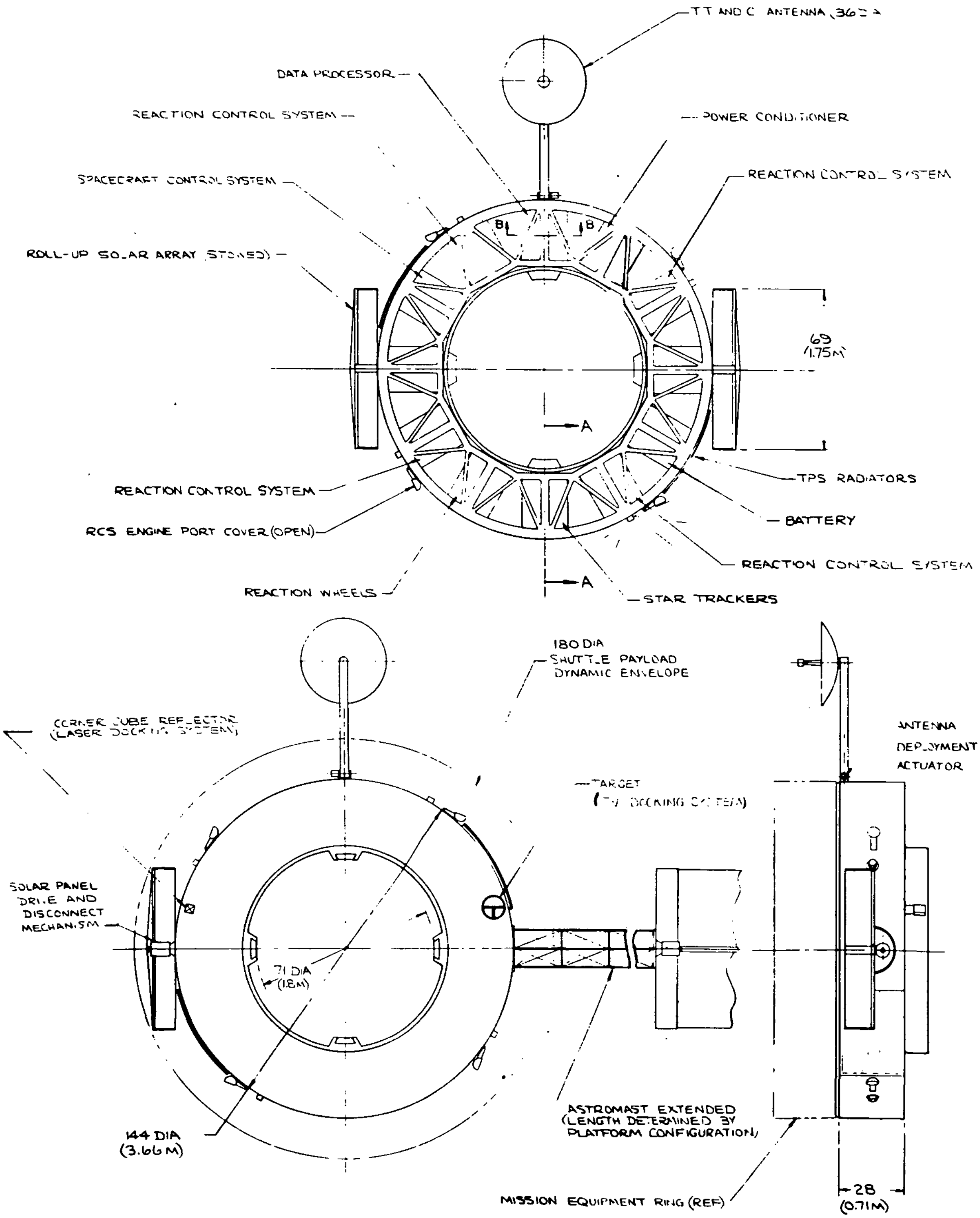


Figure 6-13. Common Support Module Configuration

Table 6-9. Support System Functional Groupings

Function	Modular Grouping	Rationale
Electrical Power	Battery pack	Failure rate "wear out"
	Solar array and drive mechanism (2)	Wear out Interface complexity
	Power conditioner	Failure rate Technology advances
Stabilization	Reaction wheels	Alignment criticality Wear out Technology advances
	Control electronics	Failure rates Technology advances Interface criticality
Attitude Determination	Star trackers and electronics	Alignment criticality Interface complexity
Attitude Control	Reaction jet quad (4), storage tanks, valves and associated plumbing	Consumables, interface complexity, safety, contamination, failure rates
	Control electronics	Failure rates Technology advances
Thermal Control	Distributed Cold plates Radiator	Impractical to modularize. All passive systems selected considered as part of basic structure
Data Processing	Central processor	Failure rates, technology advances, changing requirements
Tracking and Telemetry	Central processor	Failure rates, technology advances, changing requirements

Table 6-10. Common Support Module Characteristics

Item	Weight (lb)		Power Required (watts)	
	Subtotal	Total	Subtotal	Total
Structure		500		--
Primary	100			
Secondary	300			
Docking Mechanisms	100			
Electrical Power		1251		70
Solar Array Assemblies (2 KW)	240		10	
Power Conditioner	144		20	
Battery Pack	392		40	
Solar Array Booms	300		--	
Cabling	175			
Data Handling		70		28
Electronics	60		28	
Antenna	10		--	
Attitude Stabilization & Control		429		120
Reaction Wheels	75		30	
CCD Star Trackers	30		20	
Flight Control Electronics	44		50	
RCS Quads (4)	280		20	
Thermal Protection		39		
Radiators	26			
Cold Plates, Heat Pipes, etc.	13			
Totals		2289		218

PLATFORM SYNTHESIS

The functional grouping and requirements analyses indicated that three categories of geosynchronous platforms were practical - data relay, earth observation, and astro-physics. The mission equipment provisions for these platforms were analyzed for both traffic models.

Data Relay Platforms

Included in the general category of data relay platforms are the Comsat (Intelsat), Domsat, Traffic Control, Navigation, and TDRS satellites. Comsat, Domsat, and traffic control functions identified in the baseline traffic model can be grouped. The navigation functions identified in the new traffic model require unique placement of geosynchronous elements and can be grouped only with the traffic control functions of the new traffic model. The TDRS function is the same for both traffic models. Foreign as well as United States TDRS elements are reflected in the new traffic model. Unique geosynchronous element placement is required to maximize the coverage of low-earth-orbiting space elements and to provide a data relay link to a single ground station within a specific country. In the new traffic model, the international data relay function was referred to as Intelsat rather than Comsat. This function could be grouped with the Domsat function, but the projected data transfer requirements of the new traffic model required multiple platforms because of frequency spectrum (bandwidth) limitations. Because both functions require wide area coverage, which is a characteristic of the C-band frequency, it was decided that a more efficient platform network could be synthesized by incorporating only the Domsat or Intelsat function in any single platform. In this manner, C-band use can be maximized for both functions with minimum RF equipment complexity.

In order to provide worldwide Comsat, Domsat, and traffic control data relay capability commensurate with the satellites of the baseline traffic model, four global regions were defined. The centroids of the regions are 6°W, 110°W, 68°E, and 172°E longitude. The first region encompasses Europe, Africa, the Middle East, Atlantic Ocean, and South America. The second region includes all of the Western Hemisphere. The third region provides coverage of Africa, the Indian Ocean, and the majority of Asia. The fourth region includes eastern Asia and the Pacific Ocean. The regions were selected to maximize contiguous single platform coverage for all nations and single platform links between any two countries. The only exceptions to the selection criteria are the links between Central and South America to the East Asian nations.

The satellites of the baseline traffic model were analyzed to establish the data relay channel requirements for each global region. Table 6-11 summarizes the requirements. Two platforms were required as a minimum in each region in order to avoid solar outage of a ground station-platform link. Therefore, the regional requirements were equally divided between two platforms.

The selected transponder complement for each platform is also listed in Table 6-11. The capacities of the platform in Regions II, III, and IV are greater than the minimum requirements. A commonality in assemblies is reflected; for example, 12 channels of C-band are readily grouped into one assembly. Development of a unique 6-channel transponder for Region II was not considered to be an economical approach.

Table 6-11. Channel Requirements for the Platform Equivalent of The Baseline Traffic Model

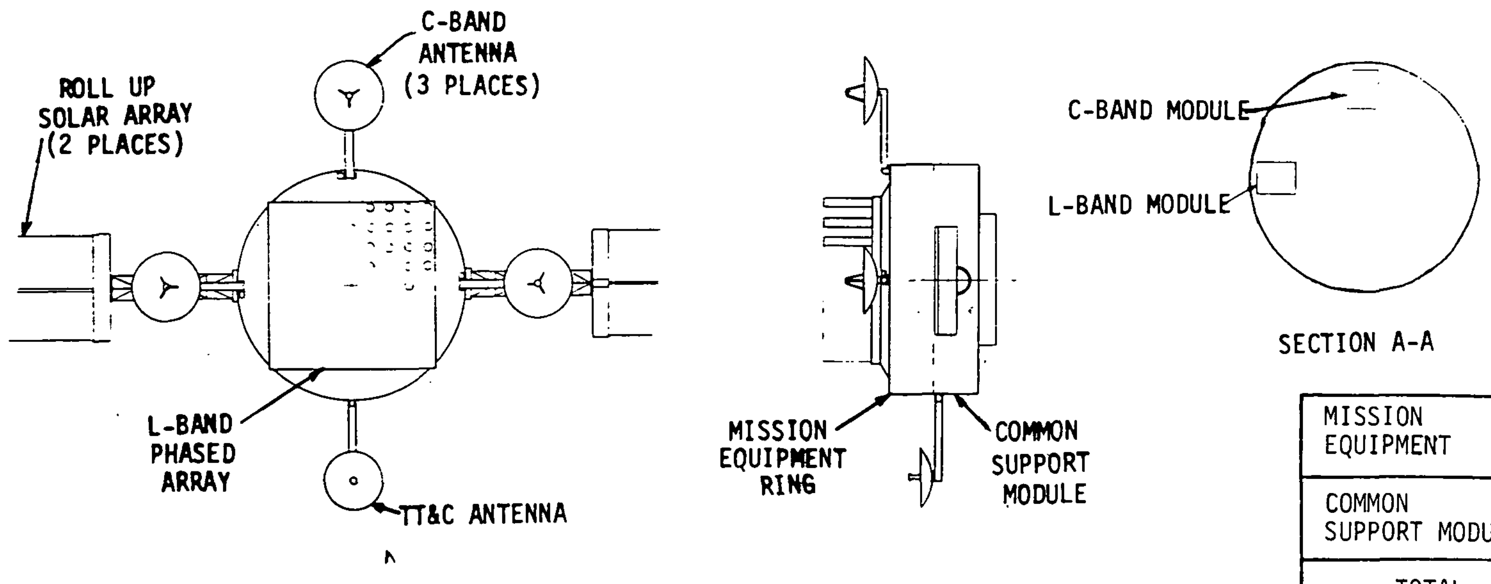
	Region I	Region II	Region III	Region IV
Channel requirements	48	60	132	288
Platform requirements	24	30	66	144
Transponder channels				
C-band	24	36	24	48
K_{LO}-band	-	-	-	24
K_{HI}-band	-	-	84	48

The traffic control function was also included on the Comsat/Domsat platform equivalents of the baseline traffic model. L-band was used as the carrier frequency. An 8.75 by 8.75-foot phased array was selected as the antenna for the platform. The concept will transfer 250 Kbps of data and is compatible with existing TACAN equipment currently used by commercial aircraft.

Figure 6-14 illustrates the Comsat/Domsat/traffic control platforms for each region. The platform weights and power requirements are also identified on the figure.

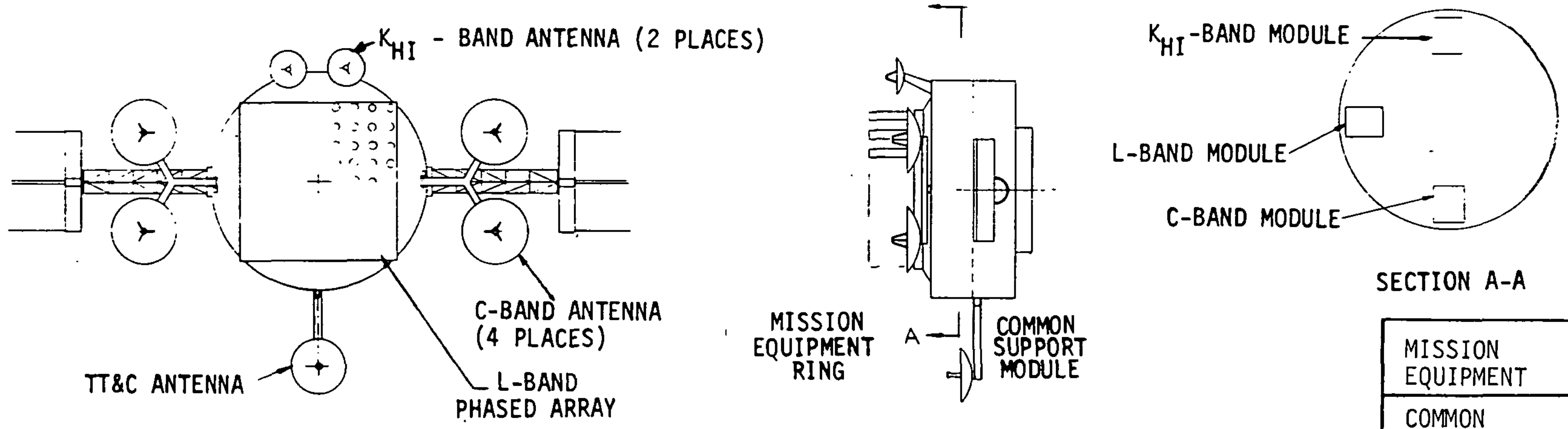
The channel requirements for each region that are commensurate with the new traffic model in the year 1990 are listed in Table 6-12. The maximum number of channels that can be accommodated on a single platform without frequency reuse are 216 (24 C-band, 24 K_{LO}-band, and 168 K_{HI}-band). Orthogonal polarization of alternate channels is included in the totals to compensate for the overlap of the passband of adjacent carrier frequencies in each band. Thus, in Region I a minimum of four Domsat and two Intelsat platforms are required. Region II requires a minimum of six Domsat and two Intelsat platforms. A minimum of five Domsat and two Intelsat platforms are required in Region III. No Intelsat requirements were defined for Region IV, but at least four Domsat platforms are required in this region.

The implementation concept is also listed in Table 6-12. The Domsat platforms for Regions II, III, and IV have a larger capacity than their respective aggregate requirements. However, to maximize the commonality of assemblies standardized 12-channel, 24-channel, and 84-channel C, K_{LO}, and K_{HI}-band transponders were utilized. Intelsat requirements were accommodated by using only C- and K_{HI}-band transponders. The apparent 48-channel shortage in Region II Intelsat capacity can be alleviated either by using the surplus 48 channels in the Domsat platform of Region II or reuse of frequencies in widely separated K_{HI}-band beams.



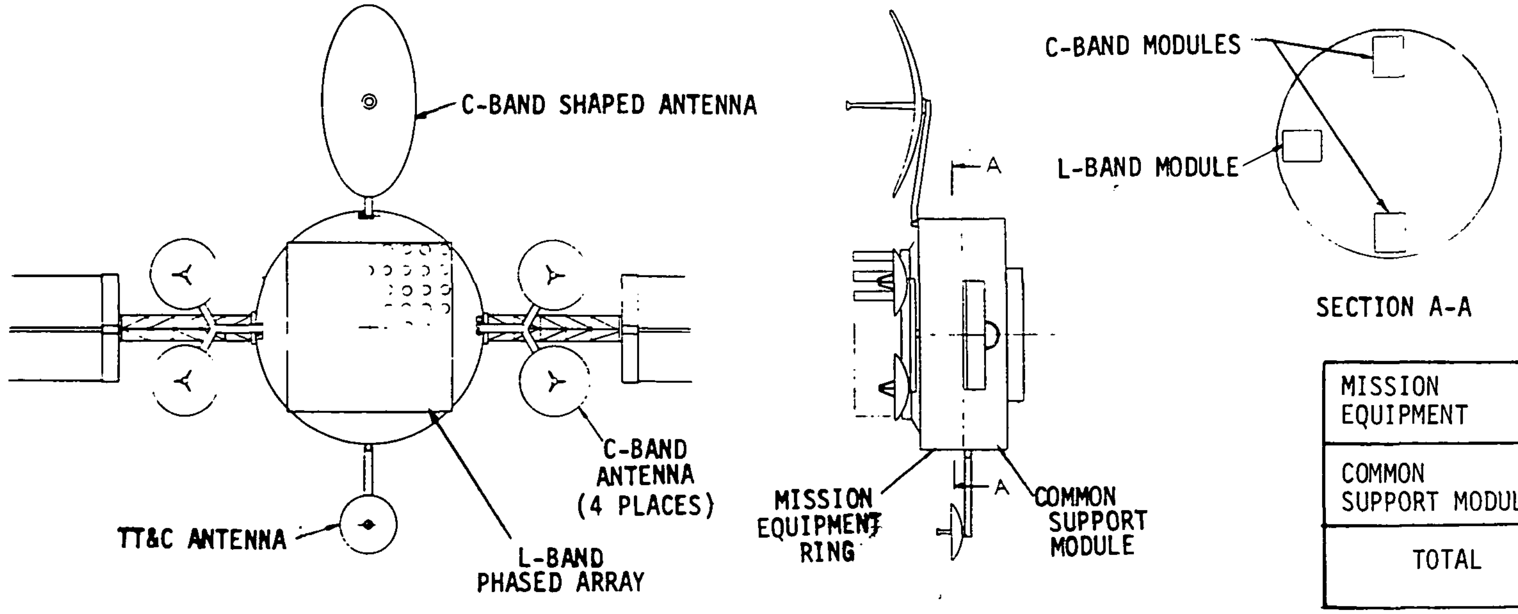
	WEIGHT (LB)	POWER (WATTS)
MISSION EQUIPMENT	770	600
COMMON SUPPORT MODULE	1989	218
TOTAL	2759	818

REGION I DATA RELAY PLATFORM



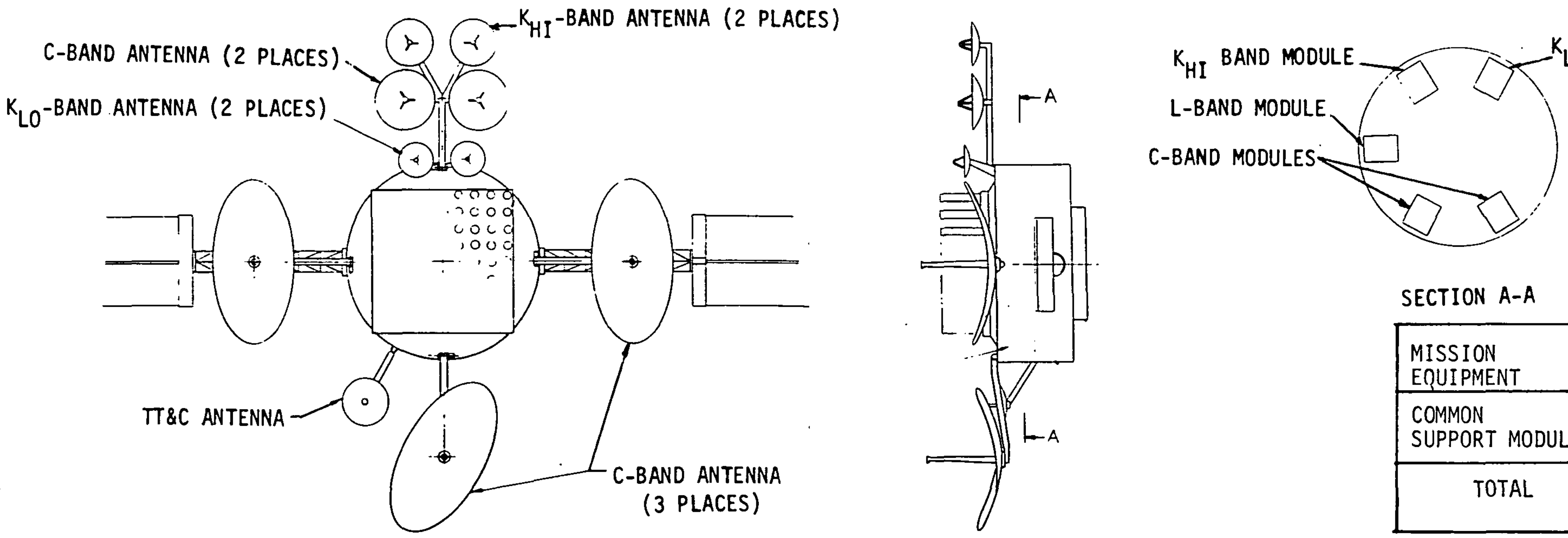
	WEIGHT (LB)	POWER (WATTS)
MISSION EQUIPMENT	1285	1080
COMMON SUPPORT MODULE	1989	218
TOTAL	3274	1298

REGION III DATA RELAY PLATFORM



	WEIGHT (LB)	POWER (WATTS)
MISSION EQUIPMENT	997	1200
COMMON SUPPORT MODULE	1989	218
TOTAL	2986	1418

REGION II DATA RELAY PLATFORM



	WEIGHT (LB)	POWER (WATTS)
MISSION EQUIPMENT	1846	1505
COMMON SUPPORT MODULE	1989	218
TOTAL	3835	1723

REGION IV DATA RELAY PLATFORM

Figure 6-14. Baseline Traffic Model Data Relay Platforms

Table 6-12. New Traffic Model Domsat/Intelsat Requirements

	Region I	Region II	Region III	Region IV
Channel requirements				
Domsat	432	1248	1008	816
Intelsat	360	432	264	-
Minimum platforms				
Domsat	4	6	5	4
Intelsat	2	2	2	-
Implementation concept				
Domsat (C, K_{LO}, K_{HI})	432	1296	1080	854
Comsat (C, K_{HI})	384	384	300	-

Figure 6-15 illustrates the basic configuration of the Domsat and Intelsat platforms that are the equivalent of the satellites with the same functions in the new traffic model. The specific complement of antennas varies from region to region because of the geographic variations. Also, K_{LO}-band equipment is included only in the Domsat platforms. The nominal power and weight characteristics of the platforms are also indicated on the figure.

The simplest mechanization would be to pre-assign specific channels to specific links. But this approach is not considered realistic. Accurately predicting traffic demands five to ten years in advance is not feasible. Also, fluctuations in daily business and the occurrence of special events, such as the Olympic games, could significantly alter the required channel assignments. Therefore, a channel reallocation technique that can be accomplished in real time via ground command was incorporated in all Domsat and Comsat/Intelsat platforms. Any channel within a frequency band can be switched to any antenna of that band.

In order to minimize the microwave connections that will be interrupted during on-orbit servicing operations, the transponder chain for a frequency band set including the switching matrix was packaged within one replaceable module. No problems were encountered in packaging the transponder chains for the baseline traffic model platform equivalents. However, some of the Domsat and Intelsat platform equivalents of the new traffic model required up to 16 K_{HI}-band antennas. For the proposed channel reallocation flexibility, an 84 by 16 microwave switching matrix is required. In this case, the total transponder assembly measured 25 W by 20 H by 36 inch D. Thus the assembly protrudes 12 inches into the 7-foot-diameter center of the toroid ring. By installing the K_{HI}-band transponder assemblies in compartments that are 60 degrees apart, adequate clearance is maintained for changeout in the most critical mode, auto/remote servicing.

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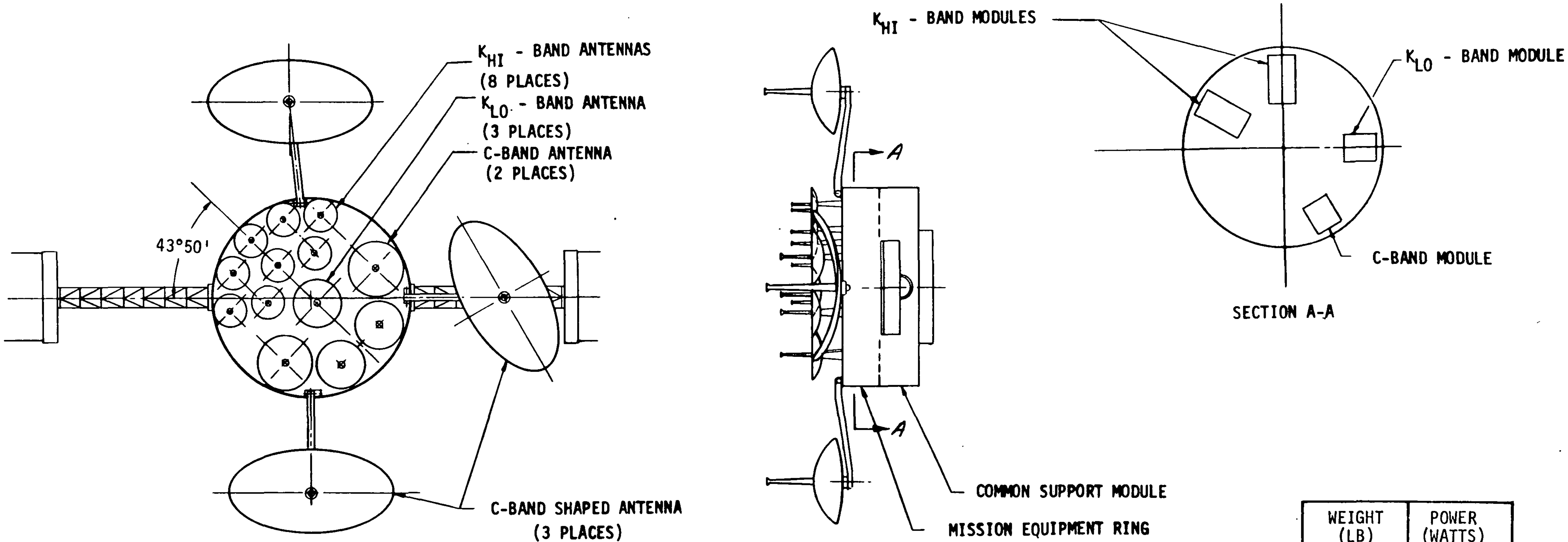


	WEIGHT (LB)	POWER (WATTS)
MISSION EQUIPMENT	2016	1385
COMMON SUPPORT MODULE	1989	218
TOTAL	4005	1603

Figure 6-15. Typical New Traffic Model Domsat/Intelsat Platform

The characteristics of the TDRS platform are presented in Figure 6-16. The same configuration is applicable for both traffic models. In essence, the platform is a repackaging of the mission equipment of the satellite to facilitate on-orbit servicing and the replacement of the customized support equipment with the common support module.

The navigation and traffic control platforms corresponding to the satellites of the same name in the new traffic model are illustrated in Figure 6-17. This platform also consists of a repackaging of the satellite mission equipment and the use of the common support module.

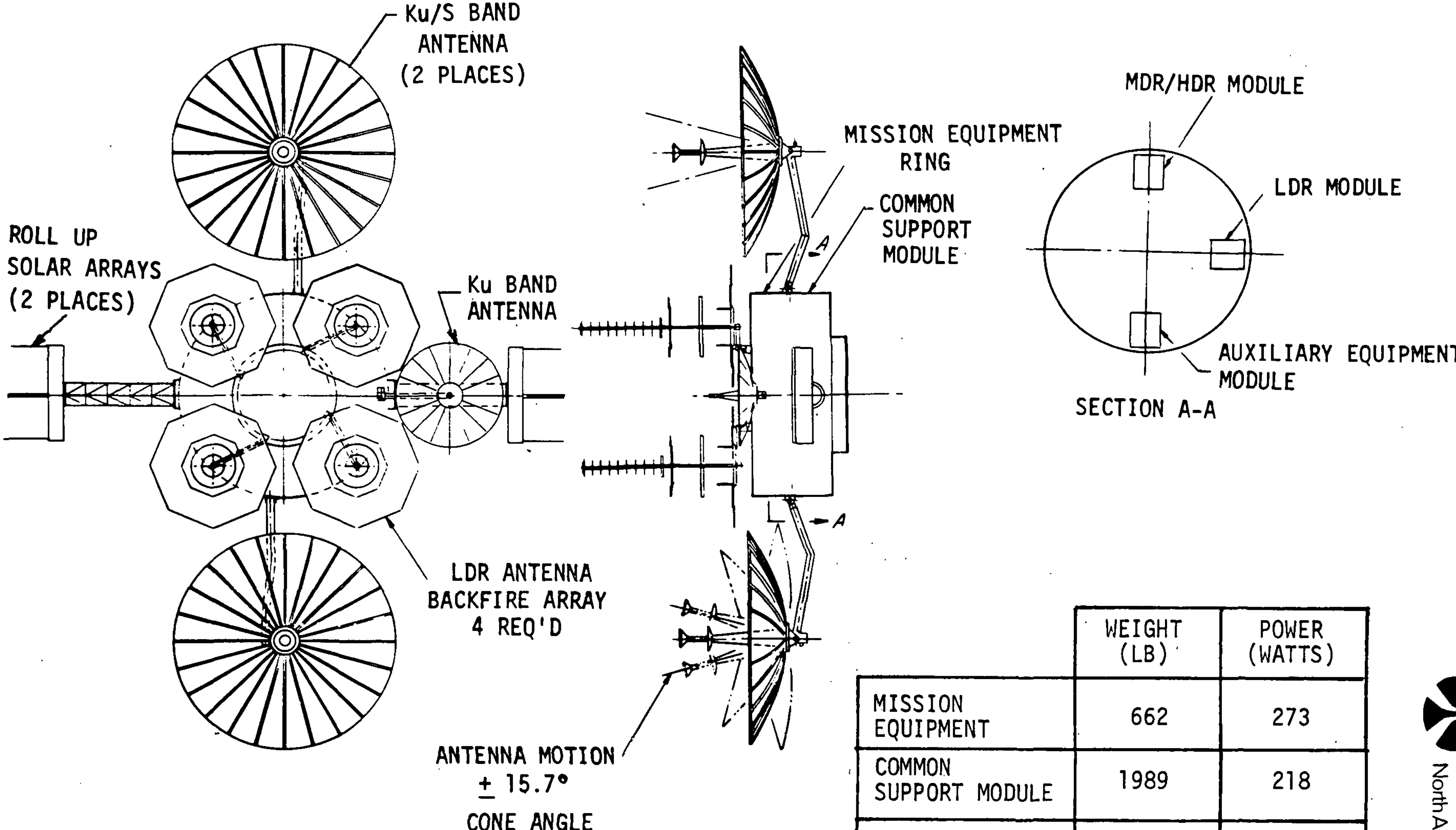
The definition of the mission equipment for the earth resource, meteorology, and astronomy satellites of the baseline traffic model was inadequate for grouping analyses. As part of the synthesis procedure, a representative series of earth observation and astronomy-physics payloads was defined. The payloads were based upon space station experiments, low-altitude satellites, and the NASA "Blue Book" of space science experiments. Scaling factors were used to adjust from low altitude to geosynchronous orbit. A total of 22 payloads was defined.

The operational requirements and mission equipment characteristics of each payload were analyzed to determine reasonable groupings. All of the earth viewing payloads were grouped on an earth observational platform, shown in Figure 6-18. Four such platforms are required to obtain the required global coverage. The primary assembly of the platform is the 1.5-meter telescope, which is required to achieve acceptable resolution of ground targets. Two mission equipment rings are required. The ring on the +Z axis contains those sensors that view the earth directly. Sensors requiring the resolution and narrow field of view of the telescope are mounted in the ring on the -Z axis. The common support module and the direct viewing equipment ring serve as a sun shade for the telescope.

Four astro-physics platforms were required because of incompatibilities of mission equipment and/or required sensor orientations. The four are: solar astronomy, stellar astronomy, plasma physics, and high-energy physics, as illustrated in Figures 6-19, 6-20, 6-21, and 6-22. The new traffic model included both foreign and U. S. astro-physics geosynchronous elements. Because of the lack of definition of the equipment of the foreign satellites, the approach taken was to assume that the foreign astro-physics mission equipment would be essentially the same as the U.S. equipment. Thus, the astro-physics platforms for foreign nations are identical to those synthesized for the U.S. space program.

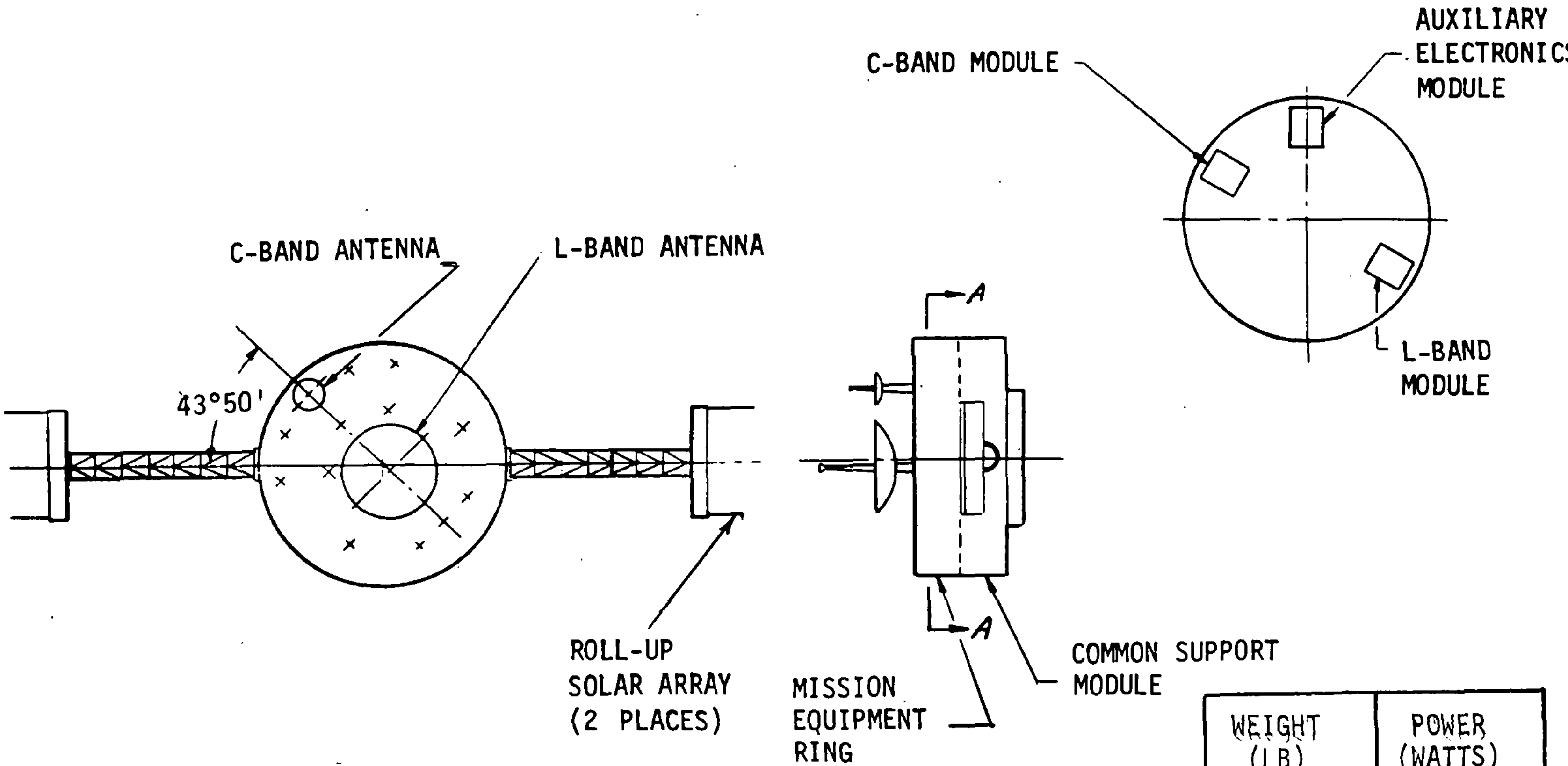
CONCLUSION

It is feasible and reasonable to group the functions of several geosynchronous satellites in a single, on-orbit serviceable platform. One platform configuration can accommodate auto/remote, EVA, and shirtsleeve servicing. That configuration, a toroid, can be utilized for both support function mission-equipment assemblies.



	WEIGHT (LB)	POWER (WATTS)
MISSION EQUIPMENT	662	273
COMMON SUPPORT MODULE	1989	218
TOTAL	2651	491

Figure 6-16. TDRS Platform



	WEIGHT (LB)	POWER (WATTS)
MISSION EQUIPMENT	810	1625
COMMON SUPPORT MODULE	1989	218
TOTAL	2799	1843

Figure 6-17. New Traffic Model Navigation and Traffic Control Platform

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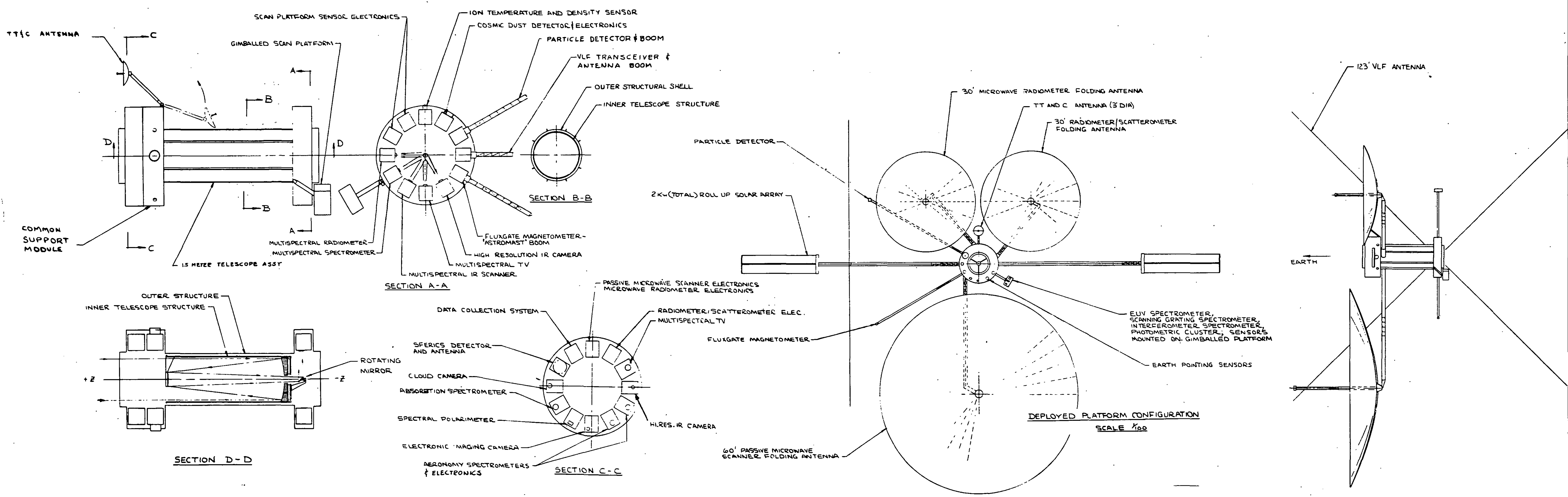
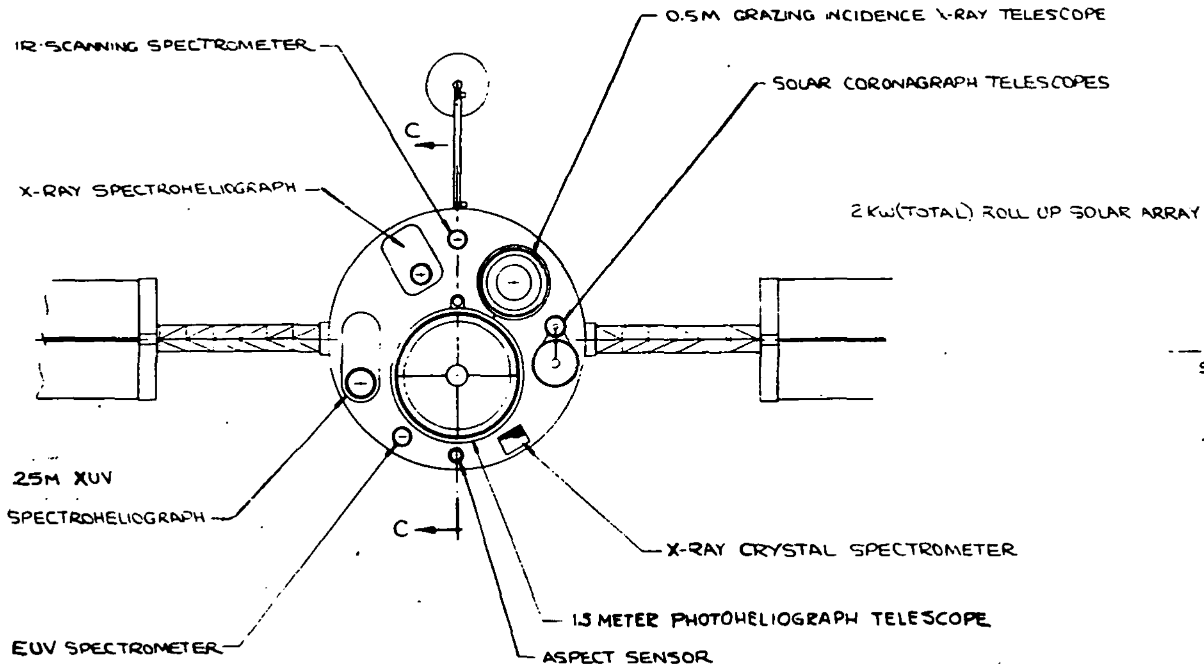
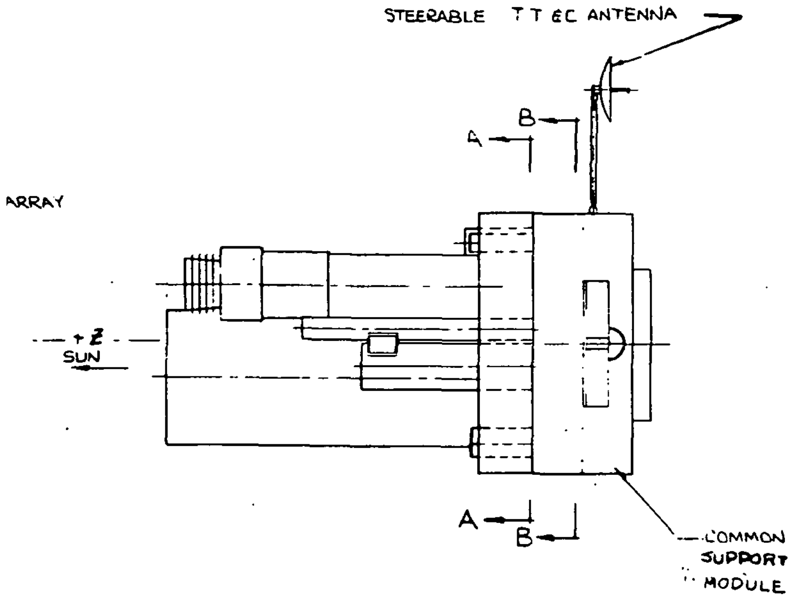


	WEIGHT (LB)	POWER (WATTS)
MISSION EQUIPMENT	6317	1736
COMMON SUPPORT MODULE	2179	218
TOTAL	8496	1954

Figure 6-18. Earth Observation Platform





	WEIGHT (LB)	POWER (WATTS)
MISSION EQUIPMENT	6179	1258
COMMON SUPPORT MODULE	2129	218
TOTAL	8301	1476

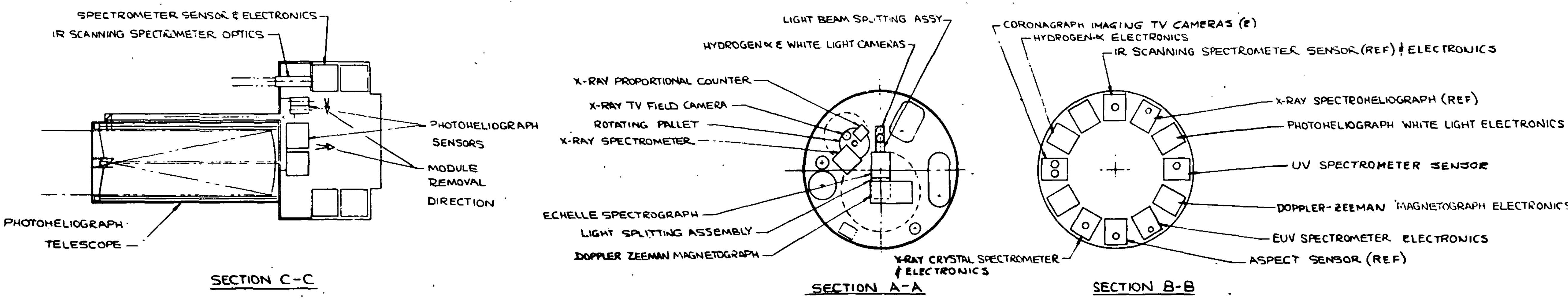
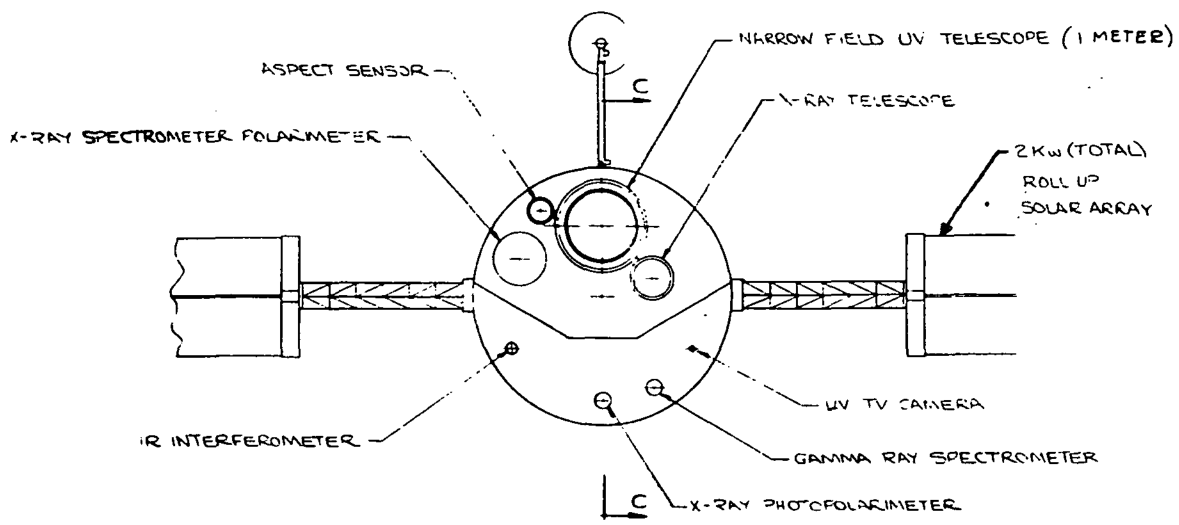
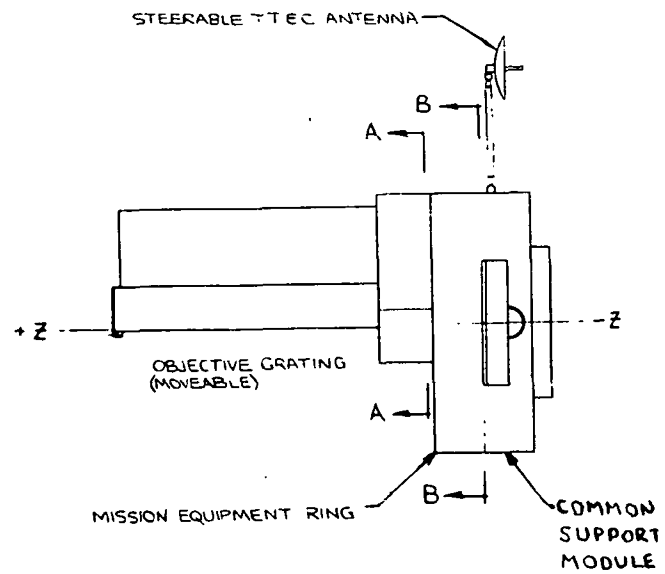
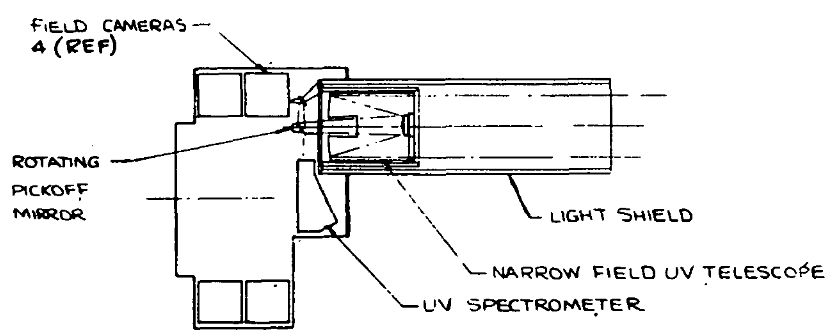


Figure 6-19. Solar Astronomy Platform

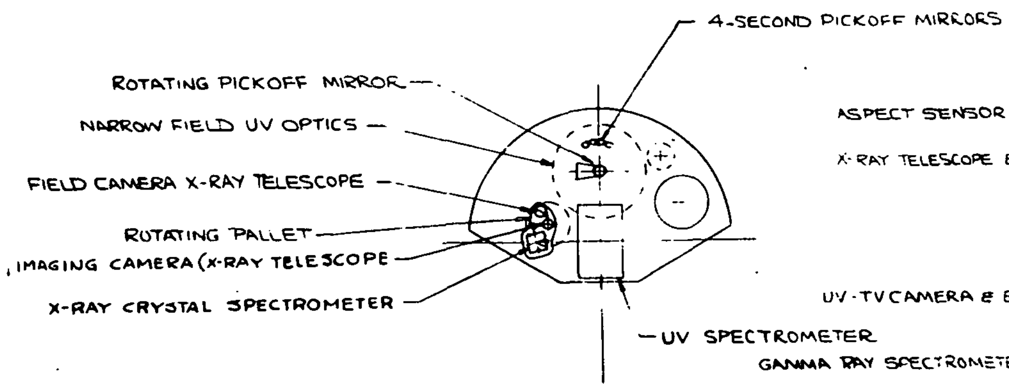




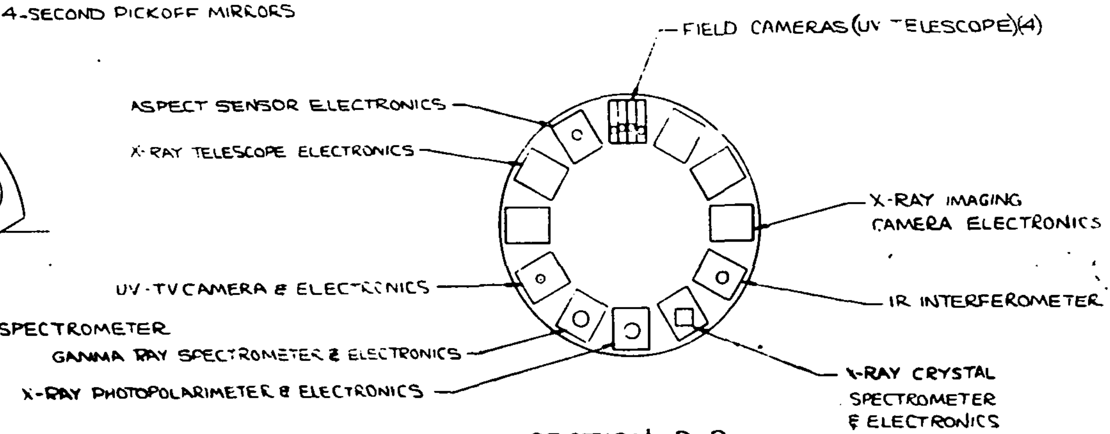
	WEIGHT (LB)	POWER (WATTS)
MISSION EQUIPMENT	3767	730
COMMON SUPPORT MODULE	2129	218
TOTAL	5896	948



SECTION C-C

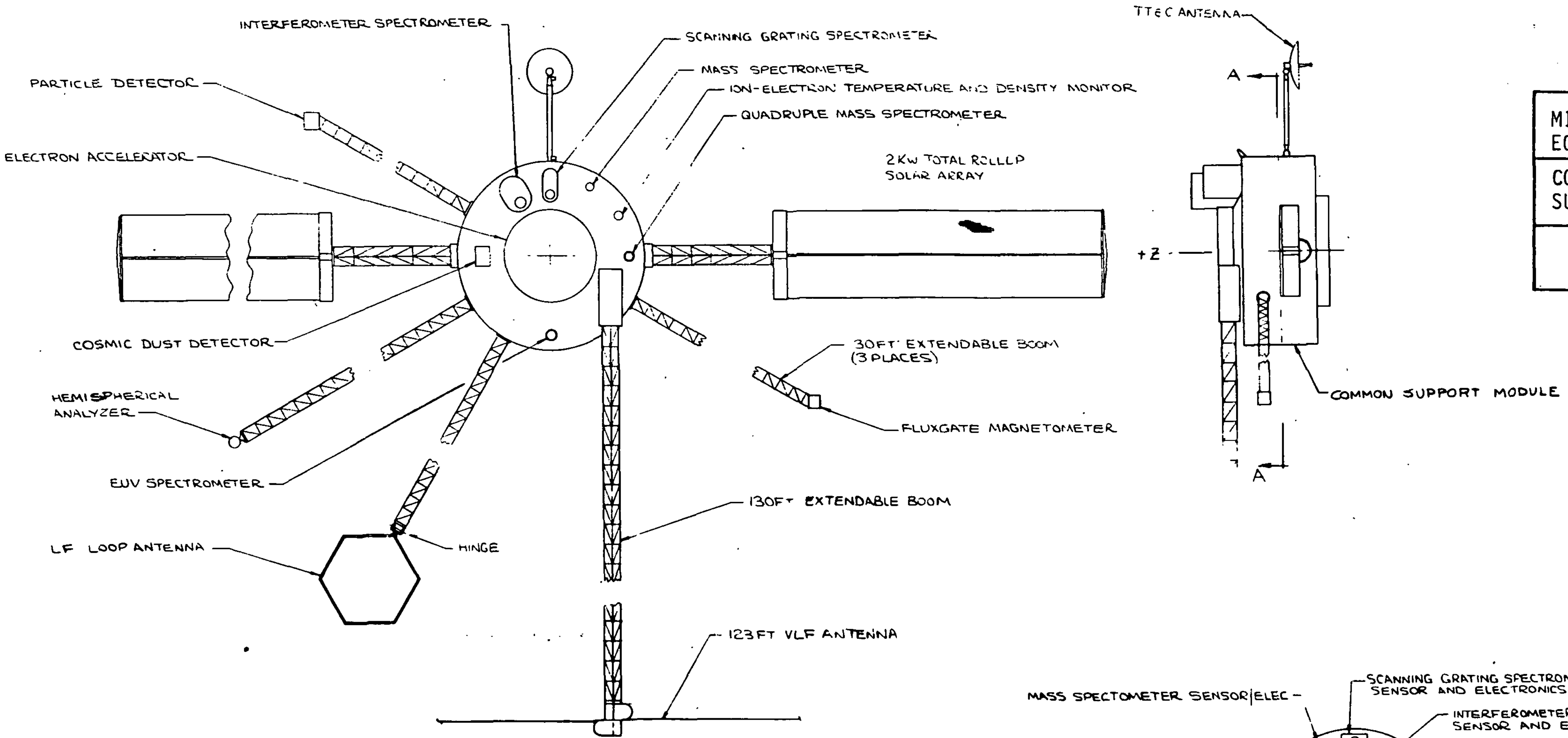


SECTION A-A



SECTION B-B

Figure 6-20. Stellar Astronomy Platform



	WEIGHT (LB)	POWER (WATTS)
MISSION EQUIPMENT	2043	1285
COMMON SUPPORT MODULE	2059	218
TOTAL	4102	1503

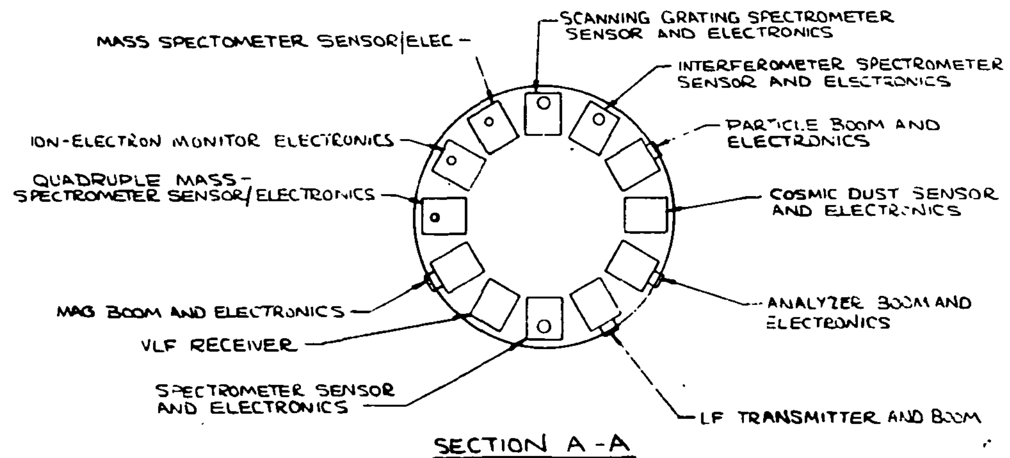
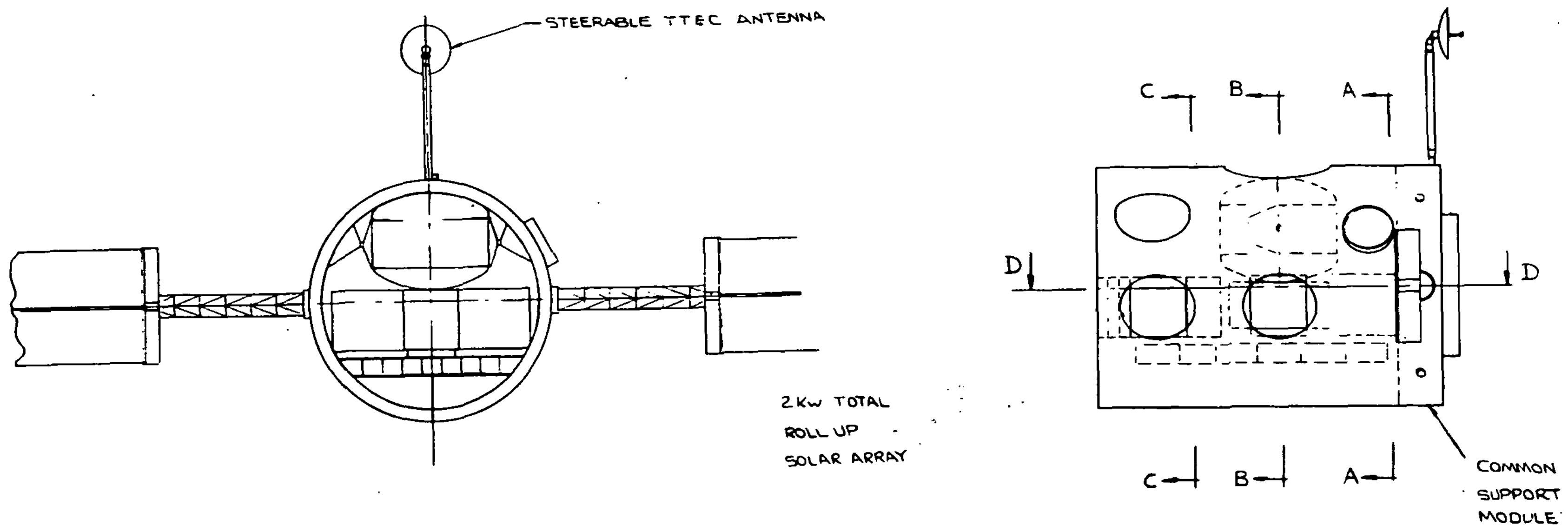


Figure 6-21. Plasma Physics Platform



	WEIGHT (LB)	POWER (WATTS)
MISSION EQUIPMENT	6370	579
COMMON SUPPORT MODULE	2129	218
TOTAL	8499	797

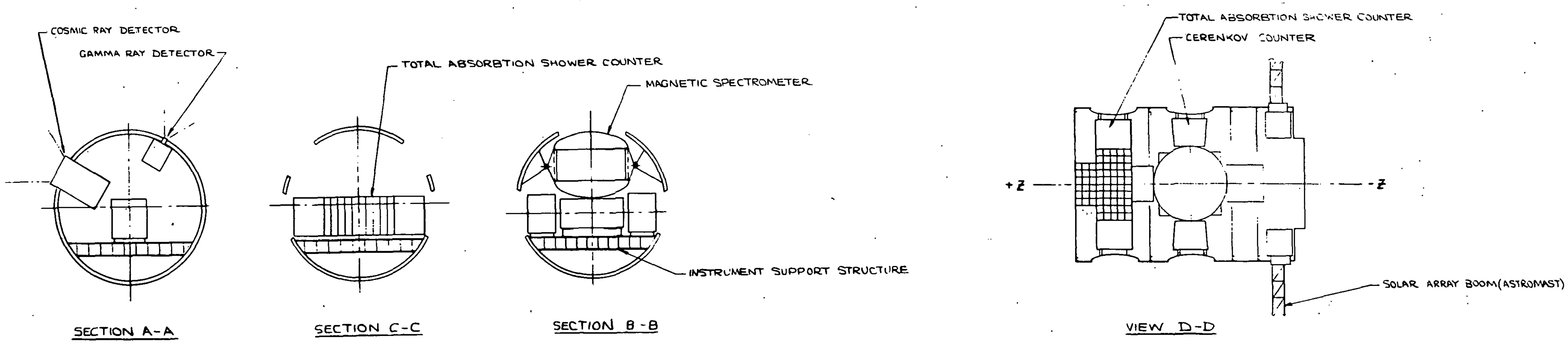


Figure 6-22. High-Energy Physics Platform

A standardized set of subsystem assemblies was derived to provide the support functions for all platforms. Table 6-13 summarizes the support systems.

Table 6-13. Common Support Subsystems

Subsystem	Assembly	Support Capability
Electrical power	Solar array (2) Battery pack Power conditioner	2K watts continuous
Attitude stabilization and control	Reaction wheels CCD star tracker Control electronics	1 arc second/second stability 10 arc second pointing
TT&C	Data processor	Directional antenna 50 Mbps downlink 20 Kbps uplink Omni antenna 64 bps uplink
Propulsion	RCS quads (4)	19,000 lb-sec impulse

Thirteen geosynchronous platforms were synthesized to meet the requirements of the satellite inventories of the two traffic models. The characteristics of the platforms, including the rationale for grouping, are summarized in Table 6-14. Platform quantities reflect the required numbers to replace the satellites listed in the traffic models from 1980 to 1990.

Table 6-14. Geosynchronous Platform Summary

Platforms \ Characteristics	Platform Weight (lb)	Platform Power (watts)	Quantity Required: Baseline Model	Quantity Required: New Model	Grouping Rationale
Data Relay Platforms					
Region I	2759	818	2	-	Global coverage, sun outage, orientation, channel capacity
Region II	2986	1418	2	-	
Region III	3274	1298	2	-	
Region IV	3835	1723	2	-	
Domsat	4005	1603	-	17	
Intelsat	3609	1478	-	6	
TDRS	2651	491	3	14	Unique placement, single national ground contact
Navigation and Traffic Control	2799	1843	-	20	Unique placement, inclined synchronous orbit
Earth Observations	8496	1954*	4	4	Orientation, maneuvers
Astro-Physics					
Solar Astronomy	6172	1476*	1	3**	Orientation and/or equipment incompatibilities
Stellar and X-Ray Astronomy	5896	948*	1	3**	
Plasma Physics	4102	1503*	1	3**	
High-Energy Physics	8499	797*	1	3**	

* Power requirement corresponds to operation of the maximum group of sensors at any one time

** Assumes that foreign astro-physics platforms are the same as U.S. platforms

7.0 TRANSPORTATION ANALYSIS

Analyses were conducted to explore the relationships between platform programs and currently defined space transportation systems. Emphasis was on the special requirements imposed by platform operations, particularly on-orbit servicing. Physical, functional, and operational interfaces were identified for all mission modes. Mission profiles and timelines were constructed to define significant events and to establish mission duration requirements for each mode. Platform interface requirements were established and compared to the available support from the defined transportation systems. Requirements for additional interface provisions were identified. Alternate methods of satisfying these additional interface needs were evaluated, and the changes imposed on the transportation systems were identified.

In addition, the applicability of solar electric propulsion (SEP) to platform programs was briefly investigated. Payload performance, operational compatibility, and potential program cost impacts were evaluated.

TRANSPORTATION INTERFACES

Interface Requirements

The interface requirements between platforms and transportation systems are primarily a function of operational modes rather than specific platform configurations. This is because of configuration similarities among all of the platform types considered in the study. All are supported by a common subsystems/utilities module which contains most of the interface provisions for the transportation system. Thus, while wide variations in mission equipment appear within the platform inventories, the platforms offer a relatively common physical interface to the transportation elements. Hence, the major interface variables are dependent upon differences in functions and operations. The following spectrum of operational modes were selected for analysis.

- Platform placement
- Auto/remote servicing
- Placement plus auto/remote servicing
- Manned servicing
- Placement plus manned servicing

Ascent profiles and mission timelines were developed for these five mission modes. Basic trajectory events and tug operations were taken from the TOPS study recently completed by Space Division. Platform-related operations, deployment, servicing, etc., were derived from pertinent configuration, subsystems, and servicing definition data contained in Volumes IV and V. The details for each mission mode were developed to a level of depth sufficient to identify the orbital transportation system (OTS) platform interfaces. For

example, Figure 7-1 relates the time history of the major functions required for the OTS/platform interface for an unmanned placement and servicing mission profile. The mission intervals during which each interface function is active are identified and interface combinations are correlated to the various mission phases and operations. These functions were analyzed to a lower level of detail to determine their method of implementation. The mission durations developed for the five modes were used to assess the impact of consumables requirements resulting from the OTS/platform interface. Required mission durations are summarized in Table 7-1.

From the above mission and configuration data, all physical, operational, and functional interfaces between the platform and OTS were identified for each of the five operational modes. These are shown in Table 7-2.

Interface provisions for placement missions require only "one-way" separation and electrical disconnects. Servicing missions add requirements for "two-way" attachment (separation and docking) and remating of electrical connectors. Similar additions are required for electrical power, ground communications, and hardwire data links. A further requirement is imposed by servicing missions in that docking is accomplished via the servicing unit rather than the tug; and manned servicing also entails atmosphere control. These principal interface requirements are summarized in Table 7-2.

The platform interface requirements were compared to the tug payload interface and support capabilities to determine additional interface needs. Representative capabilities for transportation system elements were obtained from current sources.

The unmanned tug configuration was the high-technology tug defined for the Tug Operations and Payload Support Study (TOPSS), recently completed by Rockwell International. It was designed principally for the delivery and retrieval of payloads with emphasis on autonomous operations. It was sized toward the maximum payload performance capability which could be packaged into the shuttle cargo bay while leaving sufficient space for typical payload volumes and shapes. Payload interfaces were simplified in conformance with the emphasis on autonomous operations.

Guidance and control subsystems were mechanized for the autonomous delivery and deployment of payloads with placement accuracies of 30 to 50 nautical miles in geosynchronous orbits. Attitude stabilization and payload separation tip-off dynamics were designed for expected systems needs. Onboard capability for rendezvous and docking was provided for payload retrieval and return to the shuttle. Electrical power was provided to the payload for thermal control and safety monitoring functions. Tug overall mission life was sized for a nominal six-day mission profile plus one day for contingencies. These capabilities are summarized in Table 7-3, along with the added interface needs imposed by platform configuration and operations.

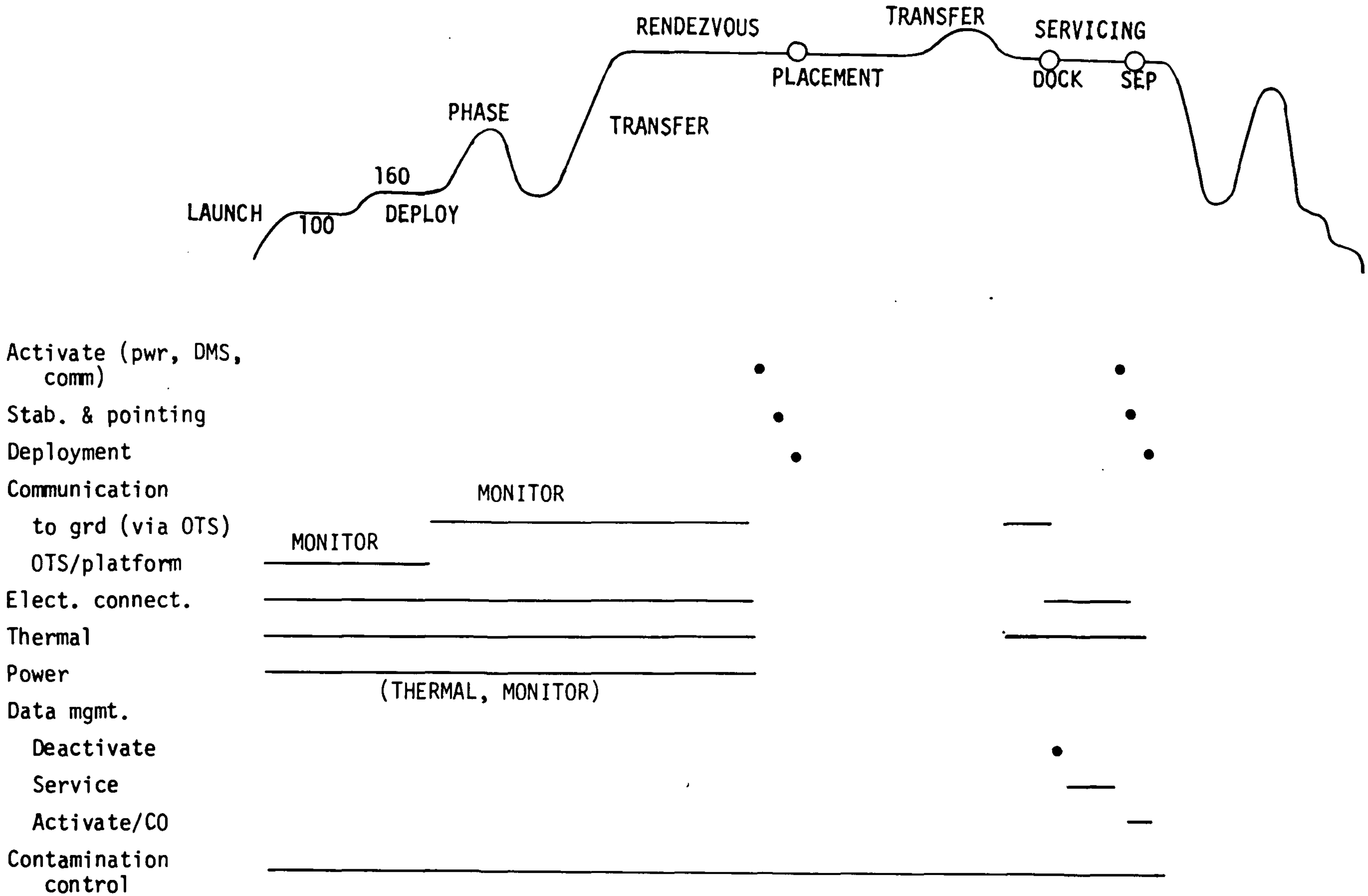


Figure 7-1. Tug/Platform Interface Identification
(Unmanned Placement and Servicing Mission)

Table 7-1. Mission Duration Summary

Operational Mode	Duration, hours
Unmanned	
Platform placement	73
Auto/remote servicing	148
Placement + auto/remote servicing	140
Manned	
Manned servicing	144
Placement + manned servicing	143

The high-technology tug selected the probe and drogue docking mechanism to meet the requirement for interfacing with spinning payloads. Alternate provisions are required with platforms to permit internal access for servicing operations.

The electrical interface provided power to the payload principally for thermal control during transit. Power for servicing operations must also be provided in the case of platform programs.

The capability of the tug to deploy a payload in geosynchronous orbit within 25 nautical miles altitude, 0.1-degree inclination, imparting no more than 0.1-g acceleration or 1 degree-per-second tip-off rate is adequate for platform operations.

Stability and pointing accuracies provided by the tug are adequate for establishing and maintaining uninterrupted communication between the platform and earth. The autonomous GN&C subsystem is sufficient to accomplish the rendezvous operation utilizing its star tracker-horizon scanner navigation system and its close-in laser radar acquisition and tracking for terminal rendezvous.

Predocking assessment by the ground is a prerequisite to mission planning. Visual inspection may be accomplished by the ground through the use of the tug television capability. The tug docking method utilizing television or a laser system with passive docking aids on the platform is adequate.

Hardwire interfaces for power, control, monitoring functions, and the RF communications required for platform auto-remote activation and servicing are not provided by the defined tug. Provisions for these requirements impact the

Table 7-2. Platform-to-Tug Interface Requirements Matrix

Interface \ Operational Mode	1. Placement	2. Auto-Remote Servicing	3. Placement/A-R Servicing	4. Manned Servicing	5. Placement/Manned Servicing
Physical Interfaces					
Docking and separation	Separation-placement	Revisit for servicing	Configurations 1 and 2	Configuration 2, shuttle compatible	Configurations 1 and 4
Electrical connector	Demateable auto-remote	Remateable auto-remote	Configurations 1 and 2	Remateable	Demateable-remateable
Operational Interfaces					
Deployment	Operational orbit placement	Post-servicing placement	Configurations 1 and 2	Configuration 2	Configurations 1 and 2
Stability and pointing by tug	Deployment, activation and checkout	Configuration 1	Configuration 1	Configuration 1	Configuration 1
Rendezvous	Not applicable	Tug/RSU with platform	Configuration 2	Configuration 2	Configuration 2
Predocking platform assessment	Not applicable	Platform configured and ready for docking operations	Configuration 2	Configuration 2	Configuration 2
Docking	Not applicable	Tug active - platform passive, auto-remote	Configuration 2	Manned docking	Configuration 4
Atmosphere control	Not applicable	Not applicable	Not applicable	Platform pressurization and circulation	Configuration 4
Post-docking servicing	Not applicable	Auto-remote from ground	Configuration 2	On-orbit manned	Configuration 4
Contamination	During transit and deployment	During servicing	Configurations 1 and 2	Configuration 2	Configurations 1 and 2
Functional Interfaces					
Power	Thermal control, activation, checkout and deployment	Platform power during servicing	Configurations 1 and 2	Platform power during servicing	Configurations 1 and 4
Communications with ground	Activation and checkout TV, data, control	Auto-remote servicing TV, data, control	Configurations 1 and 2	Ground assessment and control - data and control	Configuration 4
Data and control - hardwire	Activation and checkout to establish platform to ground control direct	Deactivation, activation, and checkout of serviced platform and establish platform to ground control direct	Configurations 1 and 2	Manned on-orbit or ground control of servicing operations	Configuration 4 and control of platform activation, checkout, and deployment

Table 7-3. Unmanned Tug Interface Capability Versus Platform Requirements

Interface	Unmanned tug capability	Platform/servicing unit requirements
Docking/separation structure	Probe and drogue	7' ID ring frame
Electrical connector	On-orbit separation only	Multiple mate and demate operations
Deployment	±25 n.mi. alt, 0.1° incl., 0.1 g accel., 1°/sec T-0 rate	Adequate
Stability and pointing	0.1°/sec, 0.2°	Adequate
Rendezvous - within 50 n.mi.	Autonomous or ground track	Adequate
Terminal rendezvous	Laser radar	Adequate - passive aids
Predocking assessment	Remote TV	Adequate
Docking	Laser or TV	Adequate - passive aids
Post-docking servicing	None	Power, data, control ground communications
Power to payload	700 watts - 40.0 kw hr	550 watts - 50 kw hr

transportation systems more than any other requirement. Adequate power levels of up to 700 watts support the platform needs, but the energy capability is insufficient to support a full placement/servicing mission.

The contamination interface between the platforms and the tug is mission-sensitive and is resolved on an individual basis.

The manned tug configuration was based on extrapolation from the unmanned high-technology tug capabilities. In the derivation of its characteristics it was assumed that manned tugs would be designed principally for on-orbit servicing missions. Man's presence was deemed unnecessary for simple deployment and retrieval operations. Thus, the manned tug was postulated to include provisions for manned servicing operations including basic crew support. It was also assumed to provide at least the same levels of payload support as defined for the unmanned tug. Table 7-4 summarizes the comparison analysis between the manned tug capabilities and the platform interface needs.

The manned tug docking mechanization must be compatible with the shuttle docking interface to permit crew ingress and egress. The electrical connector interface is a general-purpose interface adaptable to a multitude of satellites including the platform. The manned tug is designed for the purpose of servicing satellites and, therefore, possesses a general-purpose data management, monitor, and control subsystem. It can be linked to payloads through a special-purpose data interfacing adapter. Its communication with the ground in support of servicing will be identical to the method established for the unmanned tug.

Interface Implementation

Interface trades and related analyses were conducted to determine the preferred concepts for each of the interface requirements defined above. Table 7-5 summarizes the interface additions required by platforms, identifies the options available for satisfying these requirements, and presents the selected concepts. The following discussion highlights the principal evaluations and results.

The communication link between the servicing unit and ground control may be implemented by the following three options:

1. Direct to the service unit

2. Via the tug communication subsystem

3. Via the tug communication and data management subsystem

Figure 7-2 depicts Option 1, the direct communication link between the service unit and ground. This option provides a completely independent communication link paralleling the tug ground communication link. Both links must be used concurrently during servicing operations, since the tug provides the propulsion, attitude and stabilization control, and power management during docking, servicing, and separation activities. This option provides the simplest hardwire interface between the remote servicing unit and the tug,

Table 7-4. Manned Tug Interface Capability Versus Platform Requirements

Interface	Manned tug capability	Platform interface requirement
*Docking/separation	5' shuttle compatible ring frame	7' to 5' ID ring frame adapter
*Electrical connector	Power, data, and control - general purpose	Power, data, and control - platform unique
Deployment	±25 nm alt., +0.1° incl., 0.1 g accel., 1 °/sec tip-off rate	Adequate
Stability and pointing	0.1°/sec and 0.2°	Adequate
Rendezvous within 54 nm	Ground tracking - passive payload	Adequate
*Terminal rendezvous	Laser or visual	Adequate - passive aids
*Predocking assessment	Platform to tug via ground	Adequate
*Docking	Laser or visual	Adequate - passive aids
*Atmospheric control	Platform pressurization and circulation	Adequate
Post-docking servicing	General purpose DMS, monitoring and control	Adequate - special purpose DMS interfacing
Communication with ground	Voice - low data and command rates and TV	Adequate
*Power to platform	Up to 800 watts - 15 kwhrs	250 watts - 14 kwhrs, adequate

*Delta interface requirements/capability between unmanned and manned OTS

Table 7-5. Interface Trade Summary

Required Interface Additions	Implementation Options	Selected Concept
Common to both OTS's		
RF Communication to ground	1. Direct-Service Unit to Ground 2. Via tug Comm. to Ground 3. Via tug Data Mgmt. to Ground	2. Via tug Comm. to Ground
Power/Energy	1. Add fuel cell reactants 2. Add batteries	1. Add fuel cell reactants
Electrical umbilical and docking and location platforms	1. Location compatible to both OTS' 2. Redundant docking aid and umbilicals	1. Location selected which is compatible with both OTS
Unique to Unmanned Tug		
Unmanned Docking	Probe and Drogue or Ring Frame	7' Diam. Ring Frame
Unique to Manned Tug		
Manned Docking	5' Diam. Shuttle Compatible	7' to 5' Diam. Interface Adapter
Atmosphere	Provide Atmosphere & Control	Provided by Manned tug
Shuttle/Platform Interface	1. Direct - platform to shuttle 2. Via tug copper path 3. Via tug subsystems	3. Via tug subsystems except on manned servicing and placement mission - direct physical and functional

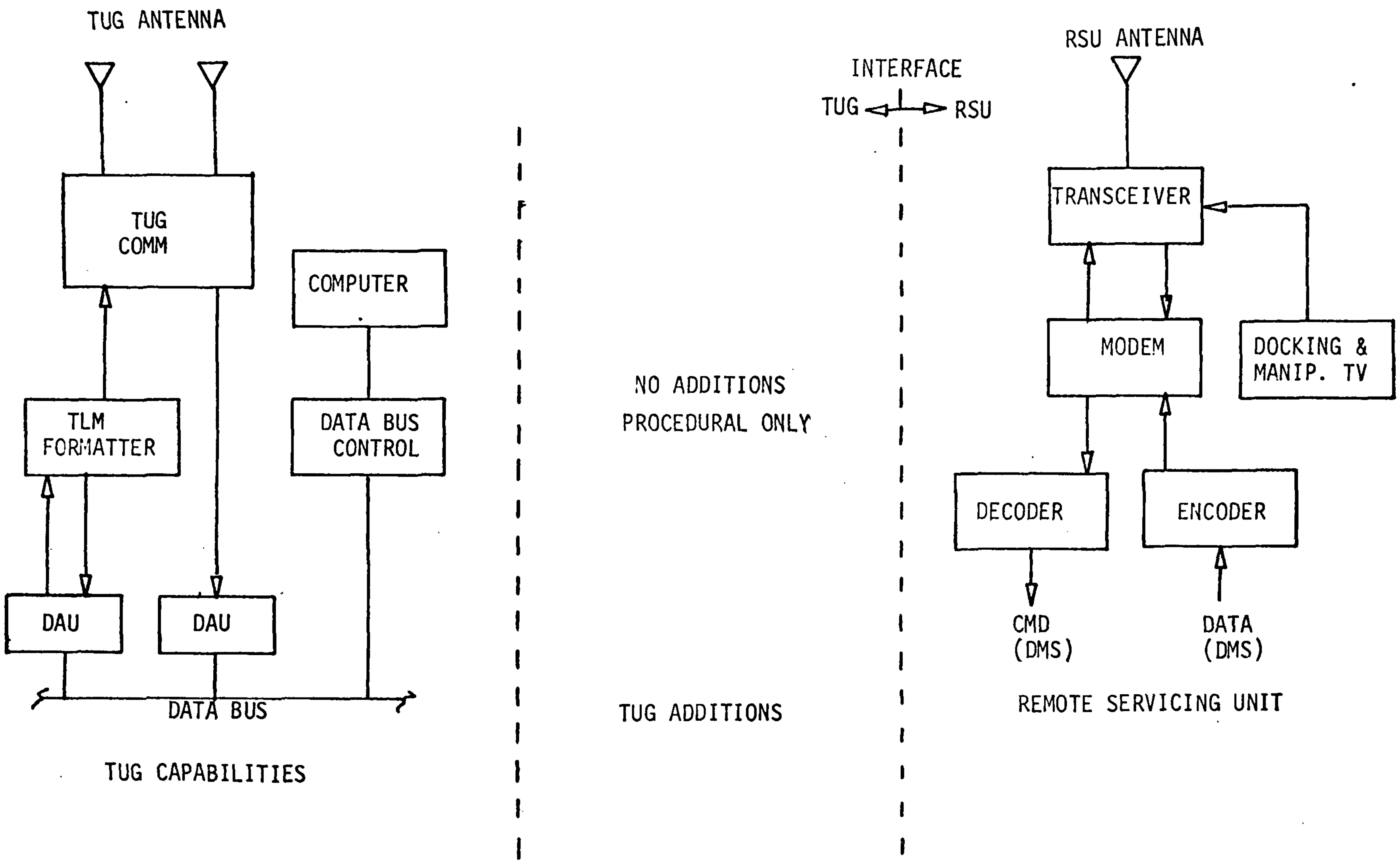


Figure 7-2. Direct Data Relay Link to Servicing Unit

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but impacts the total system by requiring two separate communication links, which double the subsystems power and weight, ground communication loads, and equipment costs.

Option 2 as depicted in Figure 7-3 modifies and utilizes the tug communication link to provide the necessary service unit RF ground control link. This option utilizes the existing tug communication television transmission capability for both the docking and the servicing operations by coax switching and routing of the television signals to the transmitter. An independent service unit telemetry data link is provided by adding a subcarrier modulator PCM data link to the tug RF multiplexer. Data rates up to 25 kbps are easily accommodated by the present-day state-of-the-art S-band communication subsystems. The tug two-kbps command uplink is used for both the tug and remote servicing unit control by interleaving coded digital commands on the single RF carrier. The added communication equipment is located in the tug to simplify the interfacing and operations of the RF equipment.

Option 3 interfaces the ground control of the service unit through the tug communication and data management system as depicted in Figure 7-4. This option minimizes the addition of equipment, but maximizes the modification of tug subsystems. This is particularly evident in the software and data management subsystem, as well as in the added ground operation complexities in the software integration and simulation impacts.

Option 1 minimizes the impact to the baseline tug, but Option 2 is preferred because it results in the least impact to the total program.

Power was sufficient from both the manned and unmanned tug subsystems, but the energy available from the unmanned tug was insufficient to conduct the potential maximum number of platform servicing missions. Adding approximately 10 pounds of fuel cell reactants to the tug satisfied the requirement with less weight impact than extra batteries.

The electrical umbilical and the docking aid on the platform were located to be compatible with both of the defined OTS vehicles (unmanned and manned).

Evolution from unmanned servicing to manned concepts will require a docking adapter which allows the smaller docking mechanism of the manned system to dock with the larger unmanned docking port. The large diameter on the common support modules is required for articulation of manipulator arms during auto-remote servicing operations. The docking adapter consists of two concentric docking mechanisms. The inner system is approximately five feet in diameter and is compatible with the space shuttle docking system. The outer mechanism is approximately seven feet in diameter and mates with the common support modules of the geosynchronous platforms.

Shuttle-to-platform hardwire interfaces are required to monitor and control platform subsystems while the platform and the tug are in the shuttle cargo bay. The options for this interface include: (1) hardline direct to the shuttle; (2) hardline through the tug to the shuttle; and (3) utilization of the established payload/tug monitor and control interface with the signals

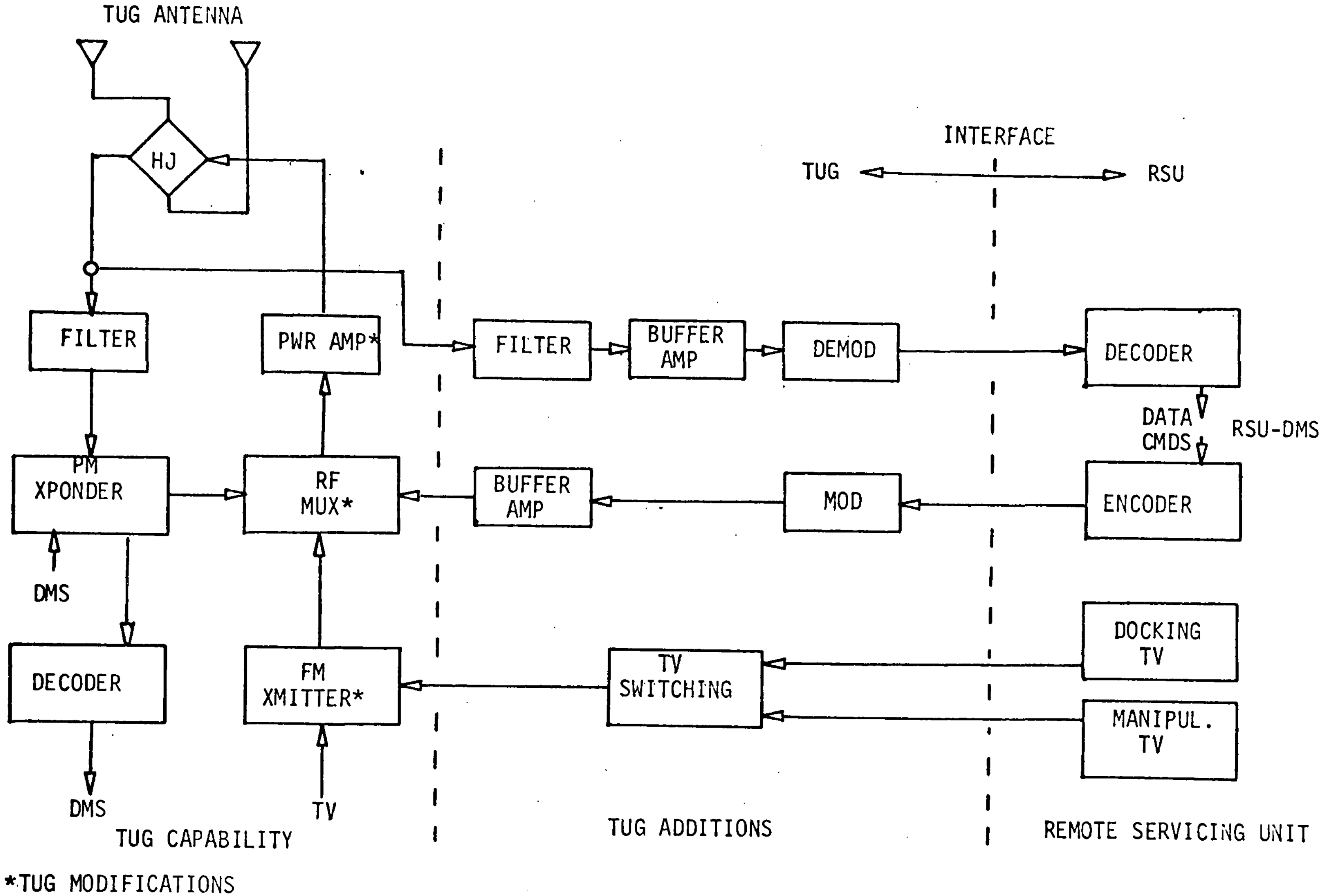

Figure 7-3. Data Relay Through Tug Communication Subsystem

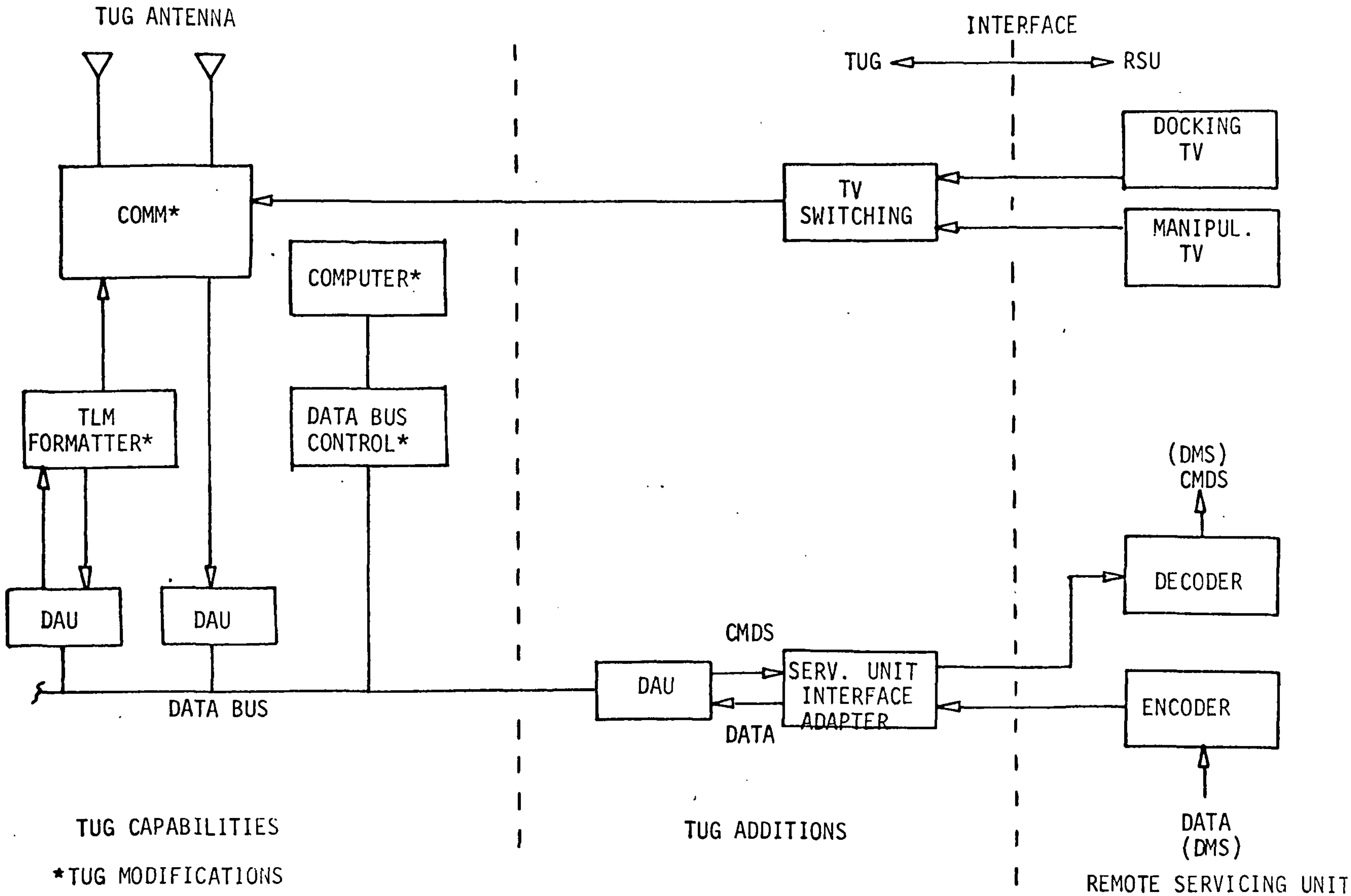

Figure 7-4. Ground Control Through Tug Comm/DMS Subsystem

carried to the shuttle via the tug data management subsystems. Option 3 was selected since these provisions are required to support mission requirements after separation from the shuttle. However, this approach can be applied only to the unmanned system. On-orbit assembly requirements for the defined two-stage, manned tug eliminate the tug-involved options. During assembly, the payload must remain in the shuttle cargo bay while the two propulsion stages are joined. Thus, for manned operations, only Option 1, direct hardline to the shuttle can satisfy the monitor and control interface needs.

SOLAR ELECTRIC PROPULSION (SEP) APPLICABILITY

As a further factor in the analysis and understanding of transportation system interfaces and requirements, the applicability of a solar electric propulsion stage (SEPS) to platform programs was briefly investigated. Although previously considered primarily for interplanetary flights, SEPS is applicable to the geo-orbital regime. The use of a geosynchronous SEPS (called Geoseps) in conjunction with the shuttle and tug was investigated in Reference 7-1. As part of the geosynchronous platform study, an evaluation of the applicability of Geoseps to geosynchronous platforms was evaluated. Geoseps stage configuration and performance characteristics from Reference 7-1 were utilized.

Geoseps Configuration and Operational Concept

The Geoseps has the unique combination of a very high I_{SP} and a high-density, non-cryogenic Mercury propellant. The nominal I_{SP} of 3000 seconds and the propellant density of 13.5 times that of water result in a design in which the propellant and tankage are not dominant elements, as they are in chemical propulsion stages. The basic Geoseps design is depicted in Figure 7-5. The key elements are the large deployable solar arrays, power conditioner panel, ion thruster array, central compartment, and docking mechanism. The solar arrays are 260 feet, tip to tip, and generate an initial total power of 25 kilowatts at 200 to 400 volts. Of this a maximum of 21 kilowatts is processed by power conditioners to operate seven 30-cm thrusters generating total thrust of 0.206 pounds. Two additional thrusters are included in the array to extend total thrust life through shared usage.

The most effective use of Geoseps for geosynchronous missions is in conjunction with a high thrust chemical stage such as the reusable tug. Direct ascent from the shuttle orbit using Geoseps alone would require extremely long mission times (several hundred days). Also, lengthy passage through the high-intensity Van Allen radiation belts would result in severe solar cell degradation.

In the preferred approach (see Figure 7-6), the tug is used to deliver the Geoseps and payload to an intermediate orbit, called the changeover orbit, from which the Geoseps propels the payload into the desired geosynchronous orbit. After placing the Geoseps into the changeover orbit, the tug returns immediately to the shuttle. Once boosted into the changeover orbit by the tug, the Geoseps performs a series of round trips between changeover and geosynchronous orbits exchanging returned payloads for new payloads to be delivered. After depletion of its propellant (536 days of thrusting operations) the Geoseps

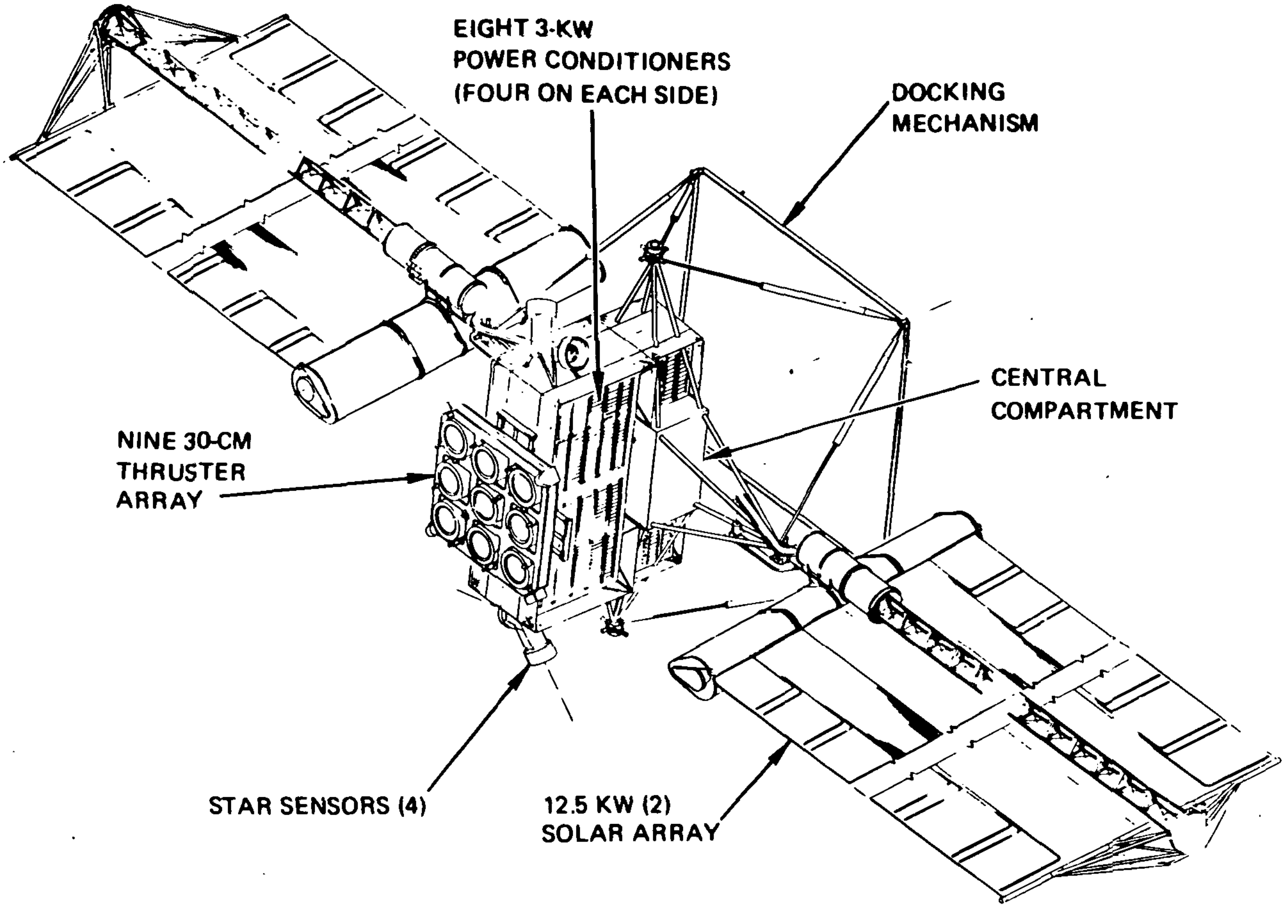

Figure 7-5. Geoseps Configuration

may be abandoned in space or returned to the ground for refurbishment. The inter-orbital operations with this mission concept are depicted in Figure 7-6. Although the reference mission shown consists of five round trips ranging from 81 to 154 days, flexibility exists to trade numbers of trips, trip time, and payload weight. Payloads in excess of 10,000 pounds can be delivered or returned. Round-trip payloads exceeding 6000 pounds can also be achieved.

Applicability Assessment

The applicability of Geoseps to platform programs was assessed in terms of payload capability, mission flexibility, compatibility with on-orbit servicing operations, and potential program cost impacts. The Geoseps payload capability greatly exceeds the requirements for platform delivery and servicing missions defined during the study. Maximum platform weights were less than 8500 pounds, compared to the more than 10,000-pound Geoseps capability defined above. Geoseps further offers the flexibility and performance capability for conducting widely-spaced servicing missions, but introduces operational and design complexities for implementation; for example, the payload exchange operations in the changeover orbit. Also, the long trip times are incompatible with manned servicing modes.

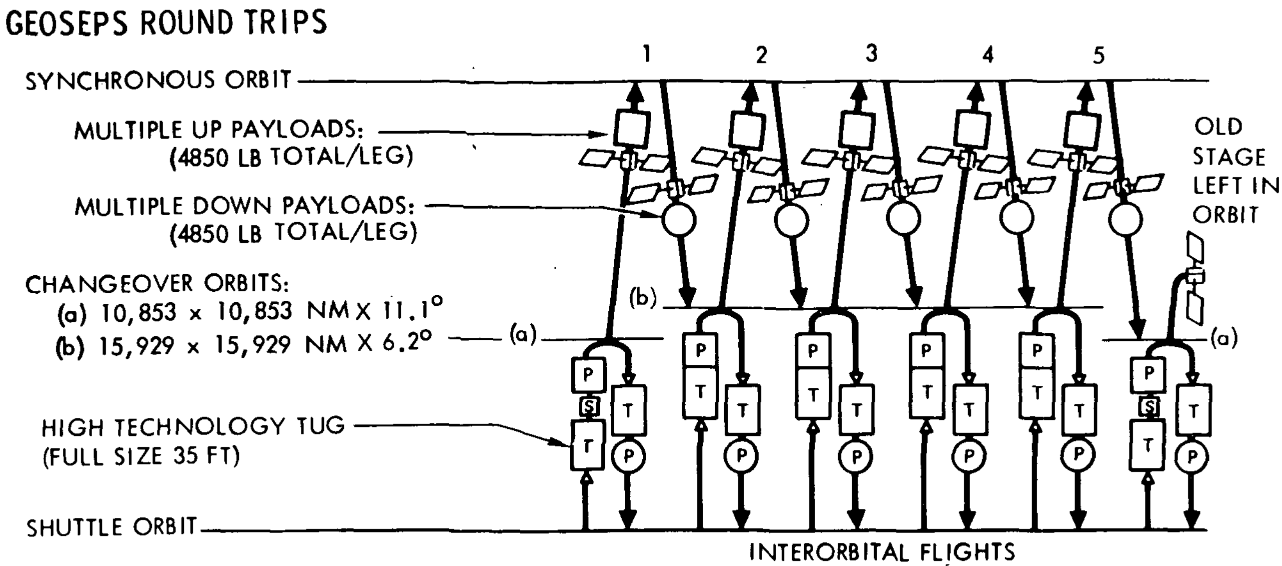

Figure 7-6. Reference Mission Schematic

The above combination of high performance and operational flexibility potentially offers reduced transportation costs through reduced numbers of shuttle/tug flights. To evaluate this potential, a representative platform program was selected from the program options derived in this study (see Table 8-1).

The selected reference program has several key features. It covers the baseline traffic model for the years 1981 through 1990. It is the multi-function platform program option, with remote servicing and a 50-percent module replacement every two years. The program comprises 18 platform deliveries and 72 update/servicing operations. When this program is used, 56 shuttle/tug flights and 2 remote servicing units are required to meet the resulting traffic and servicing needs. Total programs costs are $2784 M.

An equivalent program was constructed for the shuttle/tug/Geoseps combination. Platform deliveries and servicing schedules were held fixed as were the shuttle/tug performance and volumetric constraints. However, the extra payload capability and on-orbit life of the Geoseps were considered in the construction of a new transportation usage model. The resulting traffic characteristics are summarized in Table 7-6. Briefly, 16 missions involving mostly platform deliveries were performed by the shuttle and tug alone. An additional 19 missions were flown with the shuttle/tug/Geoseps. These were mostly servicing missions, but included the delivery of three TDRS platforms. A total of 35 shuttle flights was required, along with a cumulative Geoseps operating time of 4250 hours. With a thrust life of 536 hours, eight Geoseps were required. Also, two extra remote servicing units were required (a total of four) because of fleet impact effects associated with the long trip times.

Table 7-6. Platform Delivery and Servicing with Shuttle/Tug/SEPS

	81	82	83	84	85	86	87	88	89	90	Total
Single Tug Missions											
Delivery only	8	1	4		1	1					15
Service 2		1									1
Shuttle/Tug Flights	8	2	4		1	1					16
Geoseps Round Trips											
Delivery + 2 service			1*								1
Delivery + 3 service			2*								2
Service 3				1	1	1	1		1		5
Service 4					3		2	1	2		8
Service 5							1		1	1	3
Geoseps Operating Time (Days)	0	0	637	207	902	77	1068	126	987	246	4250
Shuttle/Tug Flights			3	1	4	1	4	1	4	1	19
Total Shuttle Flights	8	2	7	1	5	2	4	1	4	1	35
Total Deliveries	8	1	7		1	1					18
Total Service/Updates		2	8	3	15	3	16	4	16	5	72

*Three TDRS platforms delivered by Geoseps with ascent times of 80, 105, and 110 days.

Shuttle and tug alone, rather than with the Geoseps, were used for the initial platform deliveries because they fit existing cost models and do not involve the unknown factors associated with long-delivery programs. For this reason, direct tug deliveries were used in the comparative Geoseps program above. Cost impacts with the Geoseps program are summarized in Table 7-7. The use of Geoseps results in $121.5M savings in recurring transportation/servicing costs, which is 17 percent of the equivalent costs without Geoseps. Net savings are dependent upon the method employed for sharing Geoseps development costs with other programs and range between $57M and $87M for the baseline traffic model. Extrapolation to the new traffic model predicted that net savings up to $265M are possible.

Conclusions

The key findings from the above analysis are summarized as follows.

- The Geoseps offers wide flexibility in the delivery and return of payloads to and from geosynchronous orbits. Various modes may be employed, and trip time can be traded against payload weight.
- Geoseps offers long on-orbit life and performance flexibility for conducting widely-spaced servicing operations and can provided up to 20 kilowatts of electrical power for servicing operations.
- Improvements in transportation system performance due to the above factors result in significant program net cost savings, $57M to $87M (baseline traffic model) or up $265M (new traffic model).

These advantages must be weighed against the following considerations.

- The platform programs defined in this study do not require the extra payload capability offered by the Geoseps if a high technology tug is available. However, lower tug performance would require reconfigured platforms to reduce their weight or supplemental payload capability such as that offered by Geoseps.
- The use of Geoseps adds the operational complexity of payload exchange operations between the tug and Geoseps. Long trip times with Geoseps compound the mission control and fleet operation problems associated with on-orbit servicing.

It is concluded that the use of Geoseps for geosynchronous platform programs is feasible and offers significant potential cost savings as well as unique operational flexibilities. These factors must be weighed against added mission complexity, and must be analyzed in greater detail, and the application of Geoseps broadened to fully understand the implications of its use with other elements in the total National Space Program.

Table 7-7. Platform Program Cost Savings With Use of Geoseps

Cost Factors	With SEPS	Without SEPS	Delta Cost ($ M)
Number of shuttle/tug flights ($12.5 M each)	35	56	-262.6
Number of Geoseps used up ($15.0 M each)	8	-	+120.0
RSU's required ($10.57 M each)	4	2	+ 21.1

Delta recurring cost	$ -121.5M
Geoseps development	$ 35 - 65M
Net savings	$ 57 - 87M

8.0 PROGRAM EVALUATION

The characteristics of alternate geosynchronous programs were examined on the basis of the geosynchronous platform configurations, servicing concepts, and equipment definition discussed in Section 6.0. The purpose of this examination was to develop a recommended geosynchronous program approach utilizing these systems. Specifically, the shuttle/tug traffic characteristics necessary to carry out these programs were determined. Variations in servicing levels and frequency were also considered. The costs of the resultant programs were then defined and the alternate program approaches compared. Programs using conventional expendable satellites were also defined and examined only to the extent necessary to permit the comparison of these programs with on-orbit serviced platform programs. Equal time-phased, on-orbit operational capabilities were maintained within the program options for each traffic model. Platform schedules were structured to provide a total capability at least equivalent to the satellite programs they replace. However, the higher unit capacities of platforms produced slight surpluses of capability during their early years of service.

PROGRAM EVALUATION METHODOLOGY

The overall program evaluation methodology, including the identification of the necessary input data, is illustrated in Figure 8-1. A detailed discussion of the methodology and the data developed during the evaluation are contained in Volume VI, Geosynchronous Program Evaluations and Recommendations. The basic input data necessary to conduct the evaluation analyses were the traffic models and the satellite population histories discussed in Volume IV, the platform configurations and servicing concepts discussed in Volume V, and the space transportation system characteristics and capabilities discussed in Volume III.

The traffic models, plus the satellite population histories, provided the definition of the time-phased on-orbit operational capability which must be provided by the platform programs. These data, with the definition of the platform configuration concepts, provided the basis for the development of platform delivery schedules. The resultant schedules are analogous to the spacecraft delivery schedules defined by the traffic models and, as such, only identify when platforms must be delivered to retain at least the equivalent on-orbit operational capability. Multi-mission opportunities were considered to determine the required shuttle/tug traffic characteristics.

The basic program options treated in the study are outlined in Figure 8-2. The principal programs considered were the on-orbit serviced geosynchronous platform programs including both single function and multi-function platforms. For each platform class, both remote and manned servicing were considered. In order to parametrically assess the impact of the servicing operations on the total program costs, a limited set of alternate

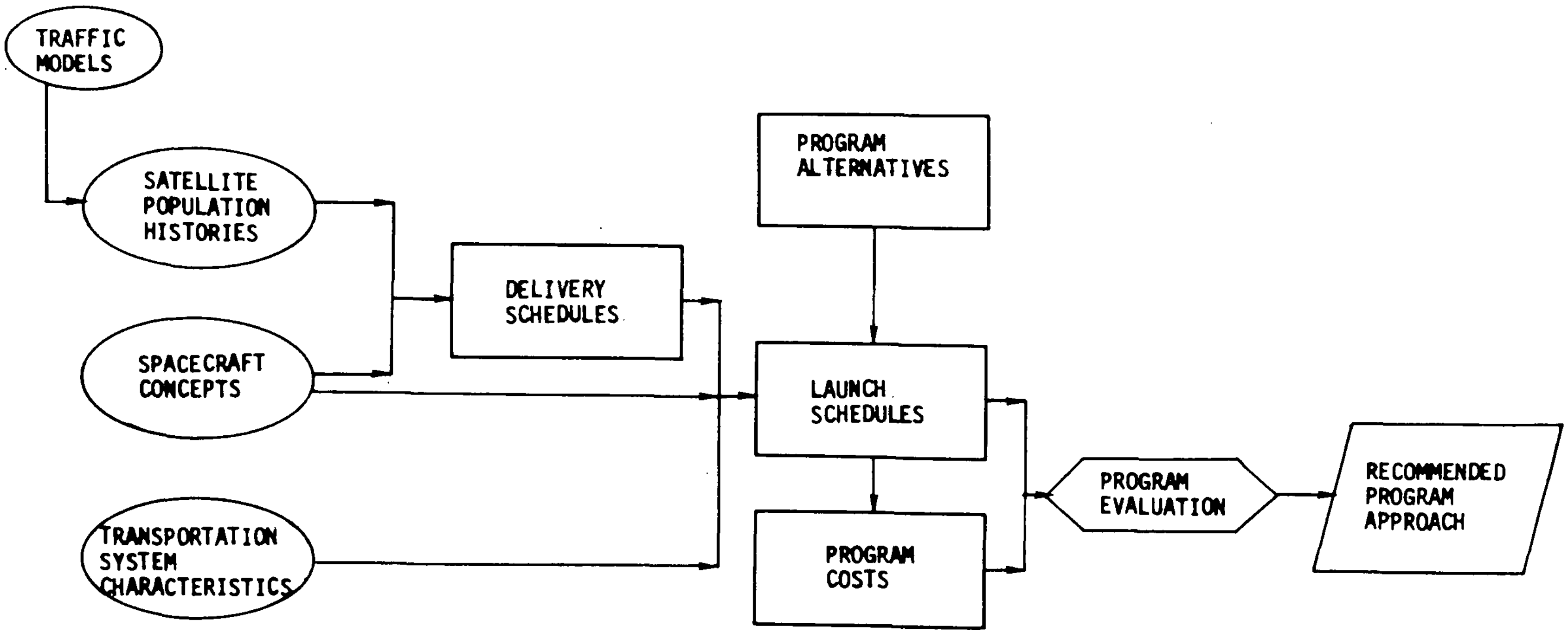

Figure 8-1. Program Evaluation Methodology

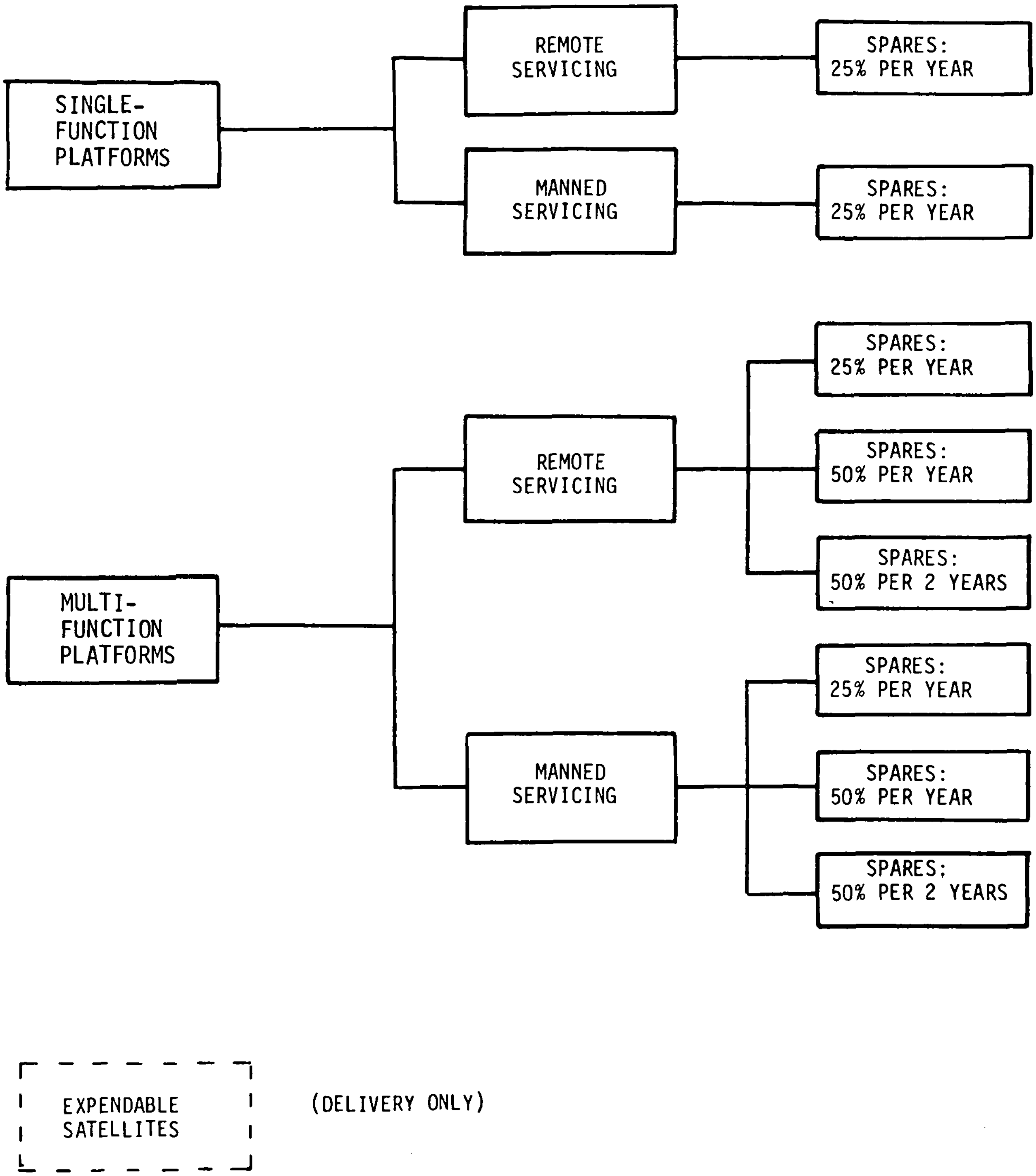

Figure 8-2. Program Alternatives

servicing levels and frequencies were examined. The values examined were selected for the purpose of establishing the impact and program sensitivity to the servicing level and frequency, and do not necessarily represent the values which will ultimately be required in an operational program. Relatively high servicing levels and frequencies were selected to ensure that the impact of these considerations would be evident.

The basic set of program alternatives resulted in the definition of eight program options. When both the baseline and new traffic models were considered, a total of 16 programs was examined. An indication of the sensitivity to the level of traffic was obtained by consideration of both traffic models. In addition to the platform programs, conventional expendable satellite programs were briefly examined for the purpose of providing a point of comparison with the platform programs. Since the fundamental purpose of this study was the definition of geosynchronous platform programs, the conventional expendable satellite programs are provided for reference only.

The shuttle/tug launch schedules required to initiate and support the program alternatives identified in Figure 8-2 were developed in light of the platform physical characteristics and the physical and performance characteristics of the space transportation systems. During the development of these launch schedules, multiple-purpose shuttle/tug flights were included when the payload requirements did not exceed the dimensional and performance constraints of the space transportation systems. For example, payload deliveries were combined with on-orbit servicing missions whenever sufficient volume was available in the shuttle cargo bay and when adequate tug performance capability was available.

Total program costs were developed on the basis of these schedules and the definition of the platform concepts. The costs of programs using conventional expendable satellites were also developed for the purpose of providing a comparison base. These data provided the basis for evaluating the alternate program approaches and developing a recommended approach.

PROGRAM COMPARISONS

The fundamental comparisons of the alternate program approaches are shown in Tables 8-1 and 8-2 for the baseline and new traffic models, respectively. The comparisons shown in these tables consider the following: (1) the total number of shuttle/tug flights; (2) the maximum annual shuttle/tug launch rates; (3) the worst-case traffic distributions in the four geographic regions defined in Section 5.0; (4) the total number of hardware end items; and (5) the total program costs for the alternate platform programs. Also shown, for comparison purposes, are the corresponding characteristics for the related conventional expendable satellite programs.

As can be seen from Tables 8-1 and 8-2, the platform programs involving remotely serviced multifunction platforms result in the lowest total program costs due to lower numbers of hardware end items and fewer shuttle/tug flights. The single function platform programs require more spacecraft on orbit than the multifunction platform programs, which cause an increase in the recurring spacecraft costs. Also, the single function platform programs require more

Table 8-1. Baseline Traffic Model Program Comparison Summary

PROGRAM CHARACTERISTIC	PLATFORM PROGRAMS								EXPENDABLE SATELLITE
	SINGLE-FUNCTION PLATFORM (25% PER YR)		MULTIFUNCTION PLATFORMS						
			REMOTE			MANNED			
	REMOTE	MANNED	25 PERCENT PER YEAR	50 PERCENT PER YEAR	50 PERCENT PER 2 YR	25 PERCENT PER YEAR	50 PERCENT PER YEAR	50 PERCENT PER 2 YR	
SHUTTLE/TUG FLIGHTS									
DELIVERY ONLY	16	21	11	11	14	15	15	16	44
DELIVERY + SERVICE	34	46	7	8	6	6	6	4	-
SERVICING ONLY	125	136	71	76	36	96	152	72	-
TOTAL	175	203	89	95	56	117	173	92	44
PEAK SHUTTLE FLIGHTS/YEAR	22	25	11	11	10	14	21	17	6
SPACECRAFT DENSITY									
REGION IV	32		7						64
REGION III	15		4						24
REGION II	8		3						12
REGION I	8		4						13
TOTAL	63	63	18	18	18	18	18	18	113
TOTAL HARDWARE END ITEMS									
CSM	63	63	18	18	18	18	18	18	-
SSM	128	128	53	53	53	53	53	53	-
RSU	9	-	3	3	2	-	-	-	-
SSM	6	-	6	6	4	-	-	-	-
CM	-	9	-	-	-	3	3	2	-
SSM	-	6	-	-	-	9	9	6	-
COSTS ($M)									
NONRECURRING	1105.0	1157.9	1105.0	1105.0	1105.0	1157.9	1157.9	1157.9	2515.3
RECURRING	3975.8	4435.2	2121.2	2354.9	1679.2	2513.2	3371.9	2157.2	2403.8
TOTAL	5080.8	5593.1	3226.2	3459.9	2784.2	3671.1	4529.8	3315.1	4919.1

Table 8-2. New Traffic Model Program Comparison Summary

PROGRAM CHARACTERISTIC	PLATFORM PROGRAMS								
	SINGLE-FUNCTION PLATFORM (25% PER YR)		MULTIFUNCTION PLATFORMS						
			REMOTE			MANNED			
	REMOTE	MANNED	25 PERCENT PER YEAR	50 PERCENT PER YEAR	50 PERCENT PER 2 YR	25 PERCENT PER YEAR	50 PERCENT PER YEAR	50 PERCENT PER 2 YR	EXPENDABLE SATELLITE
SHUTTLE/TUG FLIGHTS									
DELIVERY ONLY	36	47	30	32	36	43	42	41	122
DELIVERY + SERVICE	76	104	19	23	16	17	17	10	-
SERVICING ONLY	281	307	194	218	94	276	427	183	-
TOTAL	393	458	243	273	146	336	486	234	122
PEAK SHUTTLE FLIGHTS/YEAR	85	99	36	41	19	50	73	31	23
SPACECRAFT DENSITY									
REGION IV	49		16						70
REGION III	23		13						39
REGION II	66		14						86
REGION I	101		23						121
TOTAL	239	239	66	66	66	66	66	66	316
TOTAL HARDWARE END ITEMS									
CSM	239	239	66	66	66	66	66	66	-
SSM	478	478	159	159	159	159	159	159	-
RSU	17	-	7	7	3	-	-	-	-
SSM	16	-	14	14	6	-	-	-	-
CM	-	17	-	-	-	7	7	3	-
SSM	-	15	-	-	-	21	21	9	-
COSTS ($M)									
NONRECURRING	732.0	784.9	825.0	825.0	825.0	877.9	877.9	877.9	1,550.0
RECURRING	9,557.2	10,567.6	5,789.3	6,588.6	4,494.8	7,049.6	9,348.9	5,636.8	5,972.2
TOTAL	10,289.2	11,352.5	6,614.3	7,413.6	5,319.8	7,927.5	10,226.8	6,514.7	7,522.2

shuttle/tug flights for spacecraft delivery and on-orbit servicing, which further increases the recurring costs. The total costs of the manned servicing programs are greater than the remotely serviced programs primarily due to the increased number of shuttle/tug flights. The manned servicing missions require dual shuttle/tug launches for delivery and return of the manned servicing system. Also, total program costs are sensitive to the level and frequency of servicing. Although alternate servicing levels were not examined in detail for the single function platform programs, the trends exhibited by the multi-function platform programs are considered to be representative of the trends which can be expected.

Although costs must be a fundamental consideration in the development of a recommended program approach, other factors must also be examined. These include the programmatic flexibility provided by the platform design approach, the complexity and operational capabilities of the servicing systems, and the operational demands imposed on the space transportation systems. The impact of these considerations, which were also factors in the platform synthesis activities, are discussed briefly below.

A single platform design approach has been identified which permits a high degree of programmatic flexibility. The selected design approach, discussed in Section 6.0, will satisfy the utilities support requirements of both the baseline and new traffic models with mission functions/payloads accommodated either singularly or in judiciously selected combinations. Many important differences do exist in the integration of the various mission equipment sets, but they fall into the same general support requirements range. Therefore, a single utilities support module can be developed which will provide the necessary support for a variety of payloads. In addition, it has been determined that standardized packaging of all subsystems is feasible. These fundamental study conclusions result in the elimination of platform size as a significant programmatic variable. The selected platform design approach also provides the programmatic flexibility for an evolutionary on-orbit servicing approach from remote to manned, either suited or shirtsleeve, while minimizing the initial platform design impact.

The ability to fully exploit the potential capabilities of the selected platform design approach will depend upon a number of programmatic considerations during the operational era. An important consideration includes the potential complexities associated with the integration of mission equipment from multiple users into a single payload. This consideration extends into the payload operation when several users are involved in the operation of multiple-mission equipment sets on a single platform.

As a result of these programmatic considerations, the operational program may shift toward the single function platform concept which retains "user identity and control". User identity and control is of particular importance for international and domestic (U.S. and foreign) communications functions. In order to fully utilize the "communications commonality" potential of multi-function platforms, both international and national, particularly in the U.S. (with private ownership), cooperation will be required. Such cooperation will also be required to ensure that electromagnetic (EM) interference does not

become a problem. As discussed in Section 5.0, EM contention is likely to occur before 1990 if wider spectrum usage is not employed by communications relay satellites.

Although the multifunction, remotely serviced, platform program approach results in the lowest total program costs, the ability to fully realize this potential cost savings will depend upon the ability to design, develop, and operate the remote servicing system. The principal design driver for remote servicing systems will be the ability to clearly define servicing functions that must be performed and the level of operational flexibility that must be accommodated. The manipulator system developed will only be as "smart" as the original design ingenuity.

Of the platform programs considered, the manned servicing alternatives impose the most severe demand on the space transportation systems. The high demands are imposed primarily because of the requirement for dual shuttle/tug launches for servicing missions. Even when combined payload delivery and servicing missions are considered, the manned servicing programs still impose the most severe demands. If the shuttle/tug system is considered as a national resource, the manned servicing alternative requires a major commitment of this resource, on a yearly basis, to support an active geosynchronous program. If, during the operational era, the requirement for crew rescue is imposed, this requirement would create an even greater demand on this resource. However, man brings unique capabilities to the realm of servicing operations, including flexibility for dealing with the unexpected. Until future experience determines the true nature of on-orbit servicing needs, the capabilities inherent with man-attendance modes must be held as a viable option.

9.0 REFERENCES

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